Plant and Soil Responses to Fertilization of Grasslands in Saskatchewan, Canada and Selenge, Mongolia

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ABSTRACT

Studies were conducted at three different sites in Saskatchewan, Canada (Colonsay, Vanscoy and Rosthern) over two years (2005 and 2006) to determine the effect of dribble banded and coulter injected liquid fertilizer applied in the spring of 2005 at 56, 112 and 224 kg N ha^{-1} with and without P at 28 kg P_2O_5 ha^{-1}. A similar study was conducted in 2006 at one site in Mongolia to determine the effect of granular N and P fertilizer application on dry matter yield, and N and P concentration in plant biomass in the year of application (2006) only. The three Saskatchewan sites were unfertilized, 7-8 year old stands of mainly meadow bromegrass (*Bromus riparius*) dominated haylands, while the Mongolia site was mixed species of native rangeland.

All fertilization treatments produced significantly ($p \leq 0.05$) higher dry matter yield than the control in the year of application at the three Saskatchewan sites. The addition of 28 kg P_2O_5 ha^{-1} P fertilizer along with the N fertilizer did not have a significant effect on yield in most cases. In the year of application, increasing N rates above 56 kg N ha^{-1} did not significantly increase yield over the 56 kg N ha^{-1} rate in most cases but did increase N concentration, N uptake and protein content. A significant residual effect was found in the high N rate treatments in 2006, with significantly higher yield and N uptake. In 2005, the forage N and P uptake were in all cases significantly higher than the control in the fertilized treatments. The N uptake at the three Saskatchewan sites increased with increasing N rate up to the high rate of 224 kg N ha^{-1}, although the percent recovery decreased with increasing rate. The P fertilization with 28 kg P_2O_5 ha^{-1} also increased P uptake at the three Saskatchewan sites. The site in Mongolia was less responsive to fertilization than the three Saskatchewan sites, with only a significant response in yield, N uptake and no significant effect of P fertilization.

For incubation soil cores collected in the fall of 2006, mean respiration rates were similar among the fertilized treatments at all the sites and the pattern of CO_2 and N_2O evolution measured over a two-week period showed similar trend at the three sites, with no significant difference between treatments. However a significant increase in gas production occured as the soils were wetted during the incubation. By the fall of 2005, the fertilization effect had likely diminished along with available substrate for the soil microbial biomass.

Overall, rates of fertilizer of approximately 50 kg N ha^{-1} appear to be sufficient to produce nearly maximum yield and protein concentration of the grass in the year of application for the Saskatchewan and Mongolia sites. Surface banding placement was as effective as in soil placement and there was limited response to P fertilization. A small amount of N fertilizer that is surface-placed on these grass dominated forage systems appears to be an effective means of increasing production in the year of application. Higher rates are needed to sustain the rejuvenation beyond one year.

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DEDICATION

This thesis is dedicated to my parents, Lkhagvasuren Tsermaa and Oyun Urantsetseg.

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LIST OF ABBREVIATIONS

ANOVA	**Analysis of variance**
C	**Carbon**
CO_2	**Carbon dioxide**
d	**Day**
CH_4	**Methane**
DM	**Dry matter**
DMY	**Dry matter yield**
EC	**Electrical conductivity**
hrs	**Hours**
K	**Potassium**
LSD	**Least significant difference**
N	**Nitrogen**
N_2O	**Nitrous oxide**
NH_4	**Ammonium**
NH_4-N	**Ammonium nitrogen**
NO_3	**Nitrate**
NO_3-N	**Nitrate nitrogen**
P	**Phosphorus**
PRS	**Plant root simulator**
POM	**Particulate organic matter**
PVC	**Polyvinyl chloride**
SMB	**Soil microbial biomass**
S	**Sulphur**
SOC	**Soil organic carbon**
SOM	**Soil organic matter**
TOC	**Total organic carbon**

1.0 Introduction

Tame and native grasslands are a significant source of feed for ruminant animals. In Canada approximately 40% of the agricultural land is under perennial forage (Malhi et al., 2004), the majority of which is used for beef cattle production. Cash receipts from the sale of cattle and calves in 2005 totaling $6.4 billion or 17% of the total farm cash receipts (National Beef Industry Development Fund, 2006). Native rangeland in Mongolia is a major agricultural resource that supports the production of 30 million head of ruminant livestock. Presently, it is estimated that the agricultural sector provides 43% of employment in Mongolia with seven out of the ten jobs in the sector from livestock activities (World Bank, 2006).

Establishing seeded pasture for animal production is an important way to diversify farm income and improve the economic value of marginal land (Popp et al., 1997). In western Canada, most forage stands for grazing and hay production are established on marginal soils. Over time, the productivity and livestock carrying capacity of these hay fields and pastures may decline, largely as a result of reduced stand vigor, the invasion of unpalatable or less productive species, over grazing and poor soil fertility. To increase the productivity of old stands, producers generally break up the stand through tillage and then re-seed (Kruger, 1997). The cost of establishment of meadow bromegrass pasture is high, and was estimated in one study to be approximately Can $ 360 ha^{-1} (Kruger, 1997). Traditionally, forages are generally grown on low fertility soils and their production can be increased markedly with fertilization (Malhi et al., 2004). Rather than breaking the stand, rejuvenation of forage stands is probably the most economic and practical method to improve production and quality (Lardner et al., 2002). The effectiveness of fertilizers in increasing forage dry matter yield (DMY) and economic return is dependent upon the levels of nutrients in soil, climatic conditions, source, rate and method of fertilizer application, soil type and forage species.

It is hypothesized that old grass dominated hayland and rangeland in the semi-arid Canadian prairies and Mongolia would respond to added fertilizer in increased yield, plant and soil nutrient content and biological activity. The objectives of the research described in this thesis were to 1) determine forage stand yield and nutrient uptake as influenced by fertilization with nitrogen and phosphorus in three Saskatchewan tame grass pastures and on Mongolian native grass pasture. 2) assess the effects of fertilization on residual available soil nutrients, organic matter and production of carbon dioxide and nitrous oxide gases in an incubation.

2.0 Literature Review

Forage is the herbaceous plant material (mainly grasses and legumes) eaten by grazing animals. There are four major forage types: pasture, rangeland, hay and silage. Forage crops may consist of a single species or a grass and legume mixture. In terms of their nutritional value, legumes are rich in protein and grasses are rich in carbohydrates (Sengul, 2003). In addition, perennial grasses have widespread, extensive root systems that enhance soil organic matter, soil structure and soil aeration. Legumes fix atmospheric N into the soil and enhance the N status. An in-depth understanding of nutrient cycling through the "soil-plant-animal" system is necessary to preserve the long-term productivity and sustainability of forage systems (Chen et al., 2004). Forages require essential nutrient elements from soil for normal healthy growth (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, copper, zinc, iron, manganese, boron, molybdenum, cobalt). The amounts of these nutrients required vary considerably among forage species (Agriculture & Agri-Food Canada, 1993). This literature review covers the nature of forage systems common in the semi-arid and sub-humid regions of the prairies, their fertility requirements, management, and relation to soil properties and impact on the emission greenhouse gases.

2.1 Meadow Bromegrass (*Bromus riparius*)

In recent years, meadow bromegrass has become a popular pasture grass species for the Canadian prairies. Meadow bromegrass is a temperate-zone bunchgrass and cool-season species with long, narrow leaves. It has rapid vegetative regrowth compared to smooth bromegrass after grazing or cuttings (McCaughey, 1998; Ferdinandez and Coulman, 2001). As a result, it has become widely accepted as a pasture species, particularly in areas of the Canadian Prairies that receive between 350 to 500 mm of annual precipitation (Kruger, 1997). Meadow bromegrass starts growth approximately a week earlier in the spring than smooth bromegrass (Knowles et al., 1993). Meadow bromegrass maintains a high density of small vegetative tillers that regrow rapidly. These growing points or vegetative tillers are located below the animal grazing height, and result in meadow bromegrass being less vulnerable to frequent leaf removals (Pearen and Baron, 1996). In addition, meadow bromegrass has a more spreading and less upright architecture form than smooth brome (Figure 2.1).

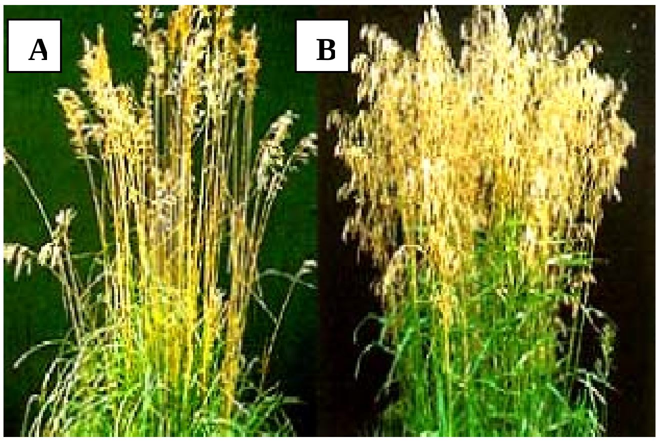


Figure 2.1. A photographic comparison of A – Meadow bromegrass; B – Smooth bromegrass
Adapted from Agriculture & Agri-Food Canada Website (http://www.agr.gc.ca/pfra/pub/forage1.htm)

Meadow bromegrass is responsive to fertilization. Meadow bromegrass yield was increased by 104-149% in the third year after establishment when it was fertilized at rate of 120 kg N ha^{-1} in Manitoba (McCaughey, 1998). In another study, fertilization with N over four years increased meadow bromegrass pasture production by 2.1 t DM ha^{-1} $year^{-1}$ (Kopp et al., 2003). However, dry conditions reduce response of meadow bromegrass to N fertilization (Loeppky and Coulman, 2002). In terms of quality characteristics, leaves of meadow bromegrass is higher in neutral detergent fiber (NDF) and acid detergent fiber (ADF), and lower in crude protein (CP) concentration than smooth and hybrid bromegrasses, regardless of the growth stage (Ferdinandez and Coulman, 2001).

2.2 Grass-legume mixtures

In forage-animal production systems, grass-legume mixtures are favoured due to several reported advantages over pure monocultures (Haynes, 1980; Chen et al., 2004; Sengul, 2003). The mixtures do impart challenges in forage management such as fertilization, height, cutting time and frequency, and maintaining the desired proportion of legume and grasses in the mixture (Baylor, 2002). The proportion of alfalfa (Medicago sativa L.) in relation to grass in the forage tends to decrease over time, and this results in a loss of nutritional value (Kopp et al., 2003). Moreover, yields are generally higher in the mixtures (Baylor, 2002) because of more efficient light utilization and the transfer of symbiotically fixed N from legumes to grasses (Ledgard, 1991). N fixation by the legume can eliminate the need for chemical N applications, and helps production of high quality forage with high protein. Besides producing more nutritious hay, it also reduces the risk of environmental pollution from the application of synthetic N sources (Gokkus et al., 1998; Sengul, 2003). In mixed forage production, dry matter yield is generally more balanced or evenly distributed throughout seasonal cuts because grasses are more productive in the spring, and legumes more productive in the summer. In addition, the more vertical nature of grass leaves vs. more horizontal leaves of legumes minimizes any inter-specific plant competition for light (Mooso and Wedin, 1990). According to Sengul (2003), the dry matter production of a legume mixed with one or two grass species under fertilized and unfertilized conditions was higher than that of pure grass stands with a high rate fertilizer applied.

The total amounts of N fixed by legumes in mixed stands should be sufficient to replace the N fertilizer applications required for grass only stand while maintaining sufficient plant protein (Chen et al., 2004). Mixtures of grass and legumes affect both above and below ground dry matter yields. The botanical composition is affected by environmental conditions, such as soil nutrient status or grazing management. This can lead to rapid changes in pasture and livestock productivity. The percentage of alfalfa in mixtures has been observed to decline with time. However, better persistence of alfalfa cultivars has been found with rotational grazing where pastures are grazed for varying periods followed by a rest period (Popp et al., 2000). On legume-grass mixed pasture, average daily gains by sheep were 0.06 kg d^{-1} compared with 0.03 kg d^{-1} on grass only pastures (Campbell, 1981). Also, milk production was higher from cows grazed in mixed pastures than in single stand pasture (Baylor, 2002).

2.3 Soil Fertility Management

2.3.1 Nitrogen (N)

Rejuvenation of pastures to increase yield production via fertilization has been studied for a number of years (Brown et al., 1960; Dodds and Van Der Puy, 1985; Ukrainetz et al., 1988; Fairey, 1991; Lardner, 1998). The decision to fertilize in a rejuvenation program must be based on the yield potential of the soils and degree of pasture deterioration (Lardner, 1998). N is the major limiting nutrient in agricultural lands (Theaker et al.,1994) and has the greatest impact on forage production (Malhi et al., 2004). N is the primary nutrient limiting forage production, but P may also be limiting in some soils (Sedivec and Manske, 1990; Berg and Sims, 1995).

A study in Manydown Estate, UK by Theaker et al. (1994) showed that fertilizer applications increased available N in the soil. However, N fertilization for grass production has been shown to be uneconomical when a moisture limitation commonly occurs (Table 2.1), such as on soils in the Brown soil zone in south-western Saskatchewan (Campbell et al., 1986).

Generally, soils with low water-holding capacities such as coarse textured, sandy soils respond poorly to fertilizer application when compared with applications on heavier-textured soils unless they have a high water table or above-normal rainfall (Lardner, 1998). Fertilization, especially with N and P, can increase dry matter production of pastureland up to two to three times depending on annual rainfall (Aydin and Uzun, 2005). On Gray Wooded (Grey Luvisol) and Black soils where available moisture is generally greater than on Brown soils, annual applications of 100 kg N ha^{-1} have increased DMY by greater than 300% when P, K and S were non-limiting (Ukrainetz and Campbell, 1988).

Similar increases have also been observed for injected liquid swine manure on brome, crested wheat (Agropyron Cristatum L.) and Russian Wild Rye (Elymus junceus) stands in east-central Saskatchewan (Pastl et al., 2000).

Table 2.1. Economic return ($ ha^{-1}) at Swift Current, SK (1981-1984) from fertilization of ammonium nitrate on grass stand at rate of 50 kg N ha^{-1} (fertilizer cost 0.68 $ kg^{-1} N, and forage price $ 85 t^{-1} DM regardless of species or forage quality).

		Time of N application					
Fertilizer	Year/ Weather	Control	Late Oct	Late Nov	Late Dec	Mid Apr	Mean
Constant forage price							
34-0-0	1981/ normal	18	1	4	-5	10	3
	1982 /wet	42	73	68	45	88	69
	1983/ normal	8	25	29	15	8	19
	1984/ dry	-24	-48	-52	-53	-52	-51

Adapted from Campbell et al., 1986.

Adequate water is required to enable photosynthesis to occur and the subsequent growth of plant tissues. N fertilizer effects on the crop will depend on the amount of rainfall during the growing season (Cohen et al., 2003). Under dry soil conditions, NO_3-N has reduced mobility in the soil, which may limit the flow of N to roots (Cohen et al., 2003).

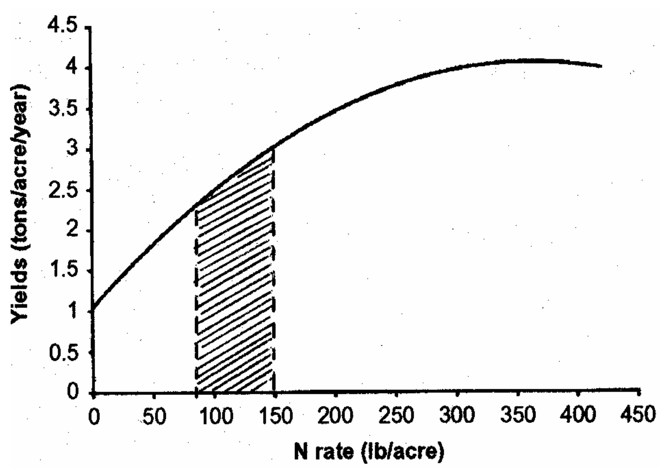


Figure 2.2. Maximum economic return from the application of nitrogen to smooth bromegrass occurs between 91 and 170 kg ha^{-1} in Missouri, USA. *Adapted from:http://www.muextension.missouri.edu*

The availability of N affects herbage yield through its influence on various aspects of the morphology and physiology of the grass plant. Factors such as tiller production, leaf area and root growth are all modified by N supply (Whitehead, 1970). Both physical response to applied N and economics must be considered when determining the most appropriate rate (Figure 2.2).

In Saskatchewan, based on the price of N fertilizer and hay, the most economical application rate was stated to be 56 kg of N ha^{-1} to a grass dominated stand, even though further dry matter responses were observed with 112 kg of N ha^{-1} in a Dark Brown Chernozem soil in Saskatchewan (Szwydky, 2005). In mixed forage stands, legumes increase N concentration in the soil due to N fixation. When a high rate of N fertilizer is applied on grass-legume forage with a 50% or greater proportion of legume, the response to added N will be limited: the legume will use the added N rather than fix it (Malhi et al., 2004). The presence of a legume might also cause a greater amount of residual N in the soil. Therefore, in mixed forage stands with a legume, natural fixation will reduce the need for N fertilizer application, either to none or to a lower rate. Forage stands that contain more than 50% legume do not require N fertilizer, whereas grass-dominated forage with one-third legume is reported to require addition of N fertilizer to optimize forage yield in Ontario (OMAF, 2002).

According to Cohen et al. (2003), much of the applied N that is not used by a forage crop in the year of application stays in the soil without significant leaching or denitrification in semi-arid soils. The residual N may contribute to higher yield for a number of years after fertilizer application has stopped, particularly in the first year after the application at high N rates. Many studies have shown that a pasture or forage with both legume and grass is difficult to remain in proper or desired balance. The stands become either grass dominated or legume dominated depending on the soil nutrient status and other forage management practices (Baylor, 2002). Although N fertilizer applications on pasture or forage increases dry matter yield, it usually causes a decrease in legume to grass ratios in the stand (Aydin and Uzun, 2005). As a result, forage quality may decline without continued high application of N. Unlike legumes, the grass dry mass ratio to biomass is increased rapidly in response to the N fertilizer application. According to Aydin and Uzun's (2005) study at Samsun, Ondokuz Mayis University Research Station, Turkey, the proportion of grass in control plots was 19-

36%, and in plots receiving 180 kg N ha^{-1} the proportion of grass increased to 61-87% (on average) during 1998-2000.

In general, soil N availability influences grass-legume competition. The increase in the proportion of grass is because N fertilizer stimulates grass growth and increases its competitive ability over legumes. Grasses have a greater relative growth rate than legumes where high soil N is available, because N promotes leafy growth of grasses. High soil N also greatly increases water use efficiency (McFarland, 2003) by increasing growth rate. Grasses are generally more tolerant than alfalfa to frequent cutting (McCaughey, 1998). In areas with low soil N availability, legumes are more competitive because they can supplement mineral N uptake with N_2 fixation. Some researchers have studied differences between N applied to forage and forage without any external N application. According to research by Gokkus et al. (1999), legume and grass mixed forage without any N fertilizer application gave yields equal to or more than grass only forage with high N application. Also, dry matter production and crude protein concentration were both higher in the mixture than in the grass or legume only pastures. Hence, they concluded that substantial yields with minimal or no use of fertilizer inputs may be sustained in grass-legume mixtures, which could otherwise only be achieved by a heavy application of N to pure grass stands. However, in moist areas heavy application of N may have leaching effects, leading to subsequent pollution of water resources (Gokkus et al., 1999).

2.3.2 Phosphorus (P), Potassium (K) and Sulphur (S)

Phosphorus can become a yield limiting factor as a result of high N fertilizer application and high yield depleting soil P supplies (Cohen et al., 2003). Baylor (2002) suggested that the application of N stimulates not only grass growth, but also results in greater uptake of P and S by grasses, increasing competition for these nutrients. Legume growth can be enhanced by addition of P fertilizers (Snyman, 2002). Applying P, K and S fertilizers increases forage dry matter yield, but has no consistent response on quality in terms of protein concentration in forage dry matter (Malhi et al., 2004). For example, a significant increase in dry matter production was achieved where the forage received both N and P fertilizer applications (Aydin and Uzun, 2005). In their study the dry matter yield of control plots was 1467 kg ha^{-1}, while 52 kg P ha^{-1} and 180 kg N ha^{-1} added as fertilizer increased yield up to 4810 kg ha^{-1}, and crude protein concentration increased.

Malhi and Dew (1987) reported that the majority of agricultural soils in the Prairies contain adequate available K. However, in a study conducted in central Alberta, they observed response to K fertilizer on bromegrass on grown on organic soils. Plant species differ in their ability to extract nutrients from soil. Alfalfa is more effective in extracting soil K than grasses such as smooth bromegrass and Russian wild rye (Bailey, 1974).

In western Canada, increased forage yield from S fertilization has been observed in some instances (Western Canada Sulphur Handbook). Malhi et al. (2000) has shown that elemental S was less effective than sulphate-S fertilizer for increasing DMY and S uptake in the initial two or three years, while it may be as effective as sulphate-S fertilizers in subsequent years, depending on the soil and climatic conditions (Table 2.2).

Table 2.2. Dry matter yield (DMY) increase of grass with one sulphate-S (Na_2SO_4) and two elemental S (Agric-Grade 0-0-0-95 and Tiger 90) fertilizers surface-broadcast annually for three years in early spring at different rates at Leslieville, Alberta (Malhi et al., 2000).

Rate of S	Na_2SO_4			Agric-Grade 0-0-0-95			Tiger 90		
(kg S ha^{-1})	year 1	year 2	year 3	year 1	year 2	year 3	year 1	year 2	year 3
	DMY increase (t ha^{-1}) in three years								
10	1.81	1.11	2.72	0.17	0.97	2.62	0.22	0.31	0.48
20	2.20	1.58	5.45	0.54	1.23	4.27	0.79	0.58	0.52
40	2.84	1.16	5.05	1.18	1.36	5.80	0.05	0.83	0.52

2.3.3 Fertilization of natural rangeland

Notable increases in the yield of natural rangeland from N fertilization have been documented by several researchers (Rogler and Russell, 1957; Wayne and Elder, 1960; Badam M, 1965; Cosper et al., 1967; Lardner, 1998). The response of native grassland to fertilization appears to vary with location in the Great Plains (Frank et al., 1968).

Fertilization of natural rangeland (native prairie species) could affect species composition differently than for tame forages (Lardner, 1998). The N fertilization of rangeland in order to increase dry matter yield results in a decrease in legume ratios in the botanical composition (Aydin and Uzun, 2005). High or moderate levels of P on native range will decrease or eliminate mycorrhizal fungi that have a symbiotic relationship with desirable grasses.

Badam (1965) conducted research to improve pasture production in the mountainous regions of Mongolia in Selenge Province from 1962-1964 at Zuunkharaa Research Station. The effect of adding fertilizer and the benefit of harrowing and additional seed planting on yield, botanical and chemical composition of three types of pastures were evaluated. The study showed that P and K fertilizers did not increase yield in the pastures. However, it was found that an application of 60 kg actual N ha^{-1} increased yield from 1.08-1.29 Mg ha^{-1} during the two years of study. Manure fertilizer (20 Mg ha^{-1}) increased the yield by 140-600 kg ha^{-1}. Plant composition was not affected by applications of P, K and manure. However, N application increased the amount of grass and reduced the amount of broad-leaf plants. In addition, Badam (1965) noted that the application of combined ($N_{60}P_{60}K_{60}$) fertilizer increased the amount of total protein in the plants by 280-430 %.

Jigjidsuren (1975) conducted research on improving mountainous steppe pasture in the central region of Mongolian People's Republic using a mechanical method in 1970-1975. He planted alfalfa (Medicago falcata), smooth bromegrass (Bromus inermus), wheatgrass (Agropyron cristatum), Siberian and Dahurian ryegrass (Elymus sibirica and Elymus Dahurian) and couch grass at an alfalfa: grass ratio of 1:2, 1:3 and 1:4 and studied the effect of fertilization. The study also included the effect of added mineral fertilizer on alfalfa planted alone. Changes in biological characteristics of perennial plants due to the effects of external environment and the nutritional regime were observed and Jigjidsuren (1975) concluded that planting alfalfa with smooth bromegrass, Siberian ryegrass and wheatgrass at a 1:2 ratio is more beneficial for the pasture and more nutritious compared to other mixtures. He also found that the application of mineral fertilizer, especially N, on alfalfa-grass pasture increased yield by 590-750 kg ha^{-1}.

A more recent study in Mongolia (Nyamdorj, 1980) examined the effect of mineral and organic fertilizers on steppe meadow, meadow and dry steppe hayfields. The study results showed that applying a mixture of the combined mineral fertilizer ($N_{60}P_{60}K_{60}$) and manure was more effective than either mineral fertilizer or manure alone. Application of N, NK and NP fertilizers in the following year increased grass yield by 20-30% while application of the mixture of manure and the combined mineral fertilizer increased yield by 50-60%.

2.3.4 Fertilizer application management

There are a number of agronomic strategies for management of fertilizers through selection of rate, form and method of application that will give best results for improving the yield and quality of pastures. These strategies are covered in this section.

Soils under long-term grassland have large reserves of organic matter built up from the constant addition and decomposition of dead above and below ground material that eventually forms humus (Mensah et al., 2003; Collins and Allinson, 2004). The potentially mineralizable N under perennial grassland after plowing has been estimated to cumulatively reach 4000 kg N ha^{-1} over 20 years (Collins and Allinson, 2004). N mineralization under unplowed perennial grassland may vary according to grass species, root development, and rates of litter decomposition, and will contribute to N availability to the forage stand. A system for measuring the actual N available should include the combination of mineralization as well as inorganic forms like nitrate and ammonium already present in soil so as to enable a more accurate rate of application of N fertilizer sufficient for optimum plant growth (Collins and Allinson, 2004).

There are a number of ways of applying fertilizer nutrients in forage fields. They are mostly dependent on the type of the fertilizer input. If it is solid manure, it must be broadcast on the forage field. Liquid manure like swine manure can be injected (Pastl et al., 2000). Commercial mineral fertilizers containing N, P, K, and S can be applied using different methods, depending on the formulation: granular or liquid. Both granular and liquid fertilizers can be placed in the seed row when the stand is being established, banded away from the seed (side-band or deep band) prior to or at the time of establishment, and broadcast on top of the soil or banded into the soil in an established stand.

Banding results in greater use efficiency of N, P and K fertilizers than broadcasting. Fertilizers can be banded after emergence (Figure 2.3) using a coulter or disk banding method (Tremblay and Panchuk, 2000).

Figure 2 3. Coulter disk for fertilizer application.

If N is applied by broadcasting, there is some risk of N becoming “hung up” in the surface if rainfall does not come soon after the broadcast. Top-dressed ammonium nitrate (34-0-0) is usually more effective than top-dressed urea (46-0-0), due to potential for additional volatile ammonia losses when urea is hydrolyzed to ammonia gas by urease enzyme on the soil surface. Dribble banding liquid urea ammonium nitrate (UAN) solution on the soil surface is considered more effective than foliar sprays (Tremblay and Panchuk, 2000). They also suggest that placing N in the soil using a spoke-wheel applicator, coulter or disc bander avoids the potential problem of N loss. However, no studies have compared surface dribble band to coultered UAN solution.

With P fertilizers, forage establishment can be improved by the placement of a high phosphate containing fertilizer in a band close to the roots, as P is immobile in prairie soils. However, a study conducted in Ponoka, Alberta by Malhi et al. (2001) to compare effectiveness of banding versus broadcasting (Table 2.3) showed that broadcasting P fertilizer was more effective than banded P fertilization.

Table 2.3. Increase in dry matter yield of bromegrass with different methods and rates of annual P fertilization

Placement Method	Rate of P (kg P ha^{-1})	DMY increase (kg ha^{-1})			
		1993	1994	1995	Mean
Broadcast	10	1146	2523	8049	3906
	20	1265	2619	8486	4123
	30	1482	3540	9641	4888
	40	1831	3294	8929	4685
Band	10	826	2206	5926	2986
	20	729	2182	7710	3541
	30	575	2834	7072	3494
	40	907	2450	8328	3895
Broadcast (mean)		1431	2994	8776	4400
Band (mean)		759	2418	7259	3479

Adapted from Malhi et al., 2001

Phosphate can be applied with the K when both are required. However, grasses or legumes usually show less incidence of K deficiency than P deficiency in Western Canadian soils (Malhi et al., 2004). K deficiency is occasionally found in alfalfa, with symptoms being small necrotic spots on the leaf, usually close to the margin of the leaflets. Phosphate deficiency symptoms are rare and non-specific in forages, but shortage of phosphate may be shown by stunting and poor winter survival of legumes (OMAF, 2000; McFarland, 2003).

2.4 Effect of Perennial Forages on Soil Properties

2.4.1 Soil organic matter

Organic matter has a role in the storage of nutrients, improving tilth, air and water movement, water retention and availability, erodibility, pesticide efficacy and decomposition processes in soil (Gregorich et al., 1994). Maintenance of adequate soil organic matter level is therefore considered imperative to sustain soil quality and agricultural productivity. According to Smith et al. (2000), Canadian soils are considered to have lost about 25-35% of their C due to cultivation and the replacement of native perennial vegetation with annual crops. On the other hand, land use change from annual crop to perennial grasses increases soil organic C level by sequestering C into the soil (Gebhart et al., 1994; Mensah et al., 2003). The particulate organic matter fraction and soil organic matter is considered an active organic matter pool that participates in the release of nutrients, and is an early indicator of the influence of management change on soil organic matter content (Cambardella and Elliott, 1992). Forages can be used to enhance soil organic matter content due to the prolific and extensive root systems that add soil organic matter and dry out the soil, reducing decomposition rate. Legumes increase soil organic N through symbiotic N fixation with rhizobial bacteria (Guretzky et al., 2004). Adding fertilizer for several years to a perennial forage pasture in central Alberta resulted in increased organic matter content (Malhi and Nyborg, 1999). Addition of liquid swine manure fertilizer also increased the light fraction of organic matter in forage grass systems in east central Saskatchewan. This increase in organic matter was attributed to increased biomass production and higher organic C inputs to the soil as a result of the fertilization (King, 2001).

2.4.2 Soil pH and electrical conductivity (EC)

Acidity in soil is determined by the measurement of the soil reaction (pH) and is a variable that impacts many different chemical and biological properties in soil (Brady and Weil, 2002; Havlin et al., 2005). Some sources of soil acidity are precipitation, CO_2 evolved from microbial respiration, nutrient uptake, leaching, clay minerals, soluble salts, and fertilizers (Havlin et al., 2005). In a forage system in central Alberta, the annual application of 100 kg N ha^{-1} of ammonium nitrate for five years lowered the pH of the soil in the 0-7.5 cm depth and this effect increased as the rate of N increased (Agriculture Agri-Food Canada, 1993).

Table 2.4. The pH of soil layers after 16 years of ammonium nitrate application at seven rates to smooth brome grass at Crossfield in south-central Alberta.

Depth (cm)	Levels of applied N (kg N ha^{-1})						
	0	56	112	168	224	280	336
	Soil pH						
0-5	7.07	6.47	5.62	4.87	4.32	4.32	4.27
5-10	7.12	7.25	7.32	7.12	6.50	6.03	5.05
10-15	7.30	7.15	6.98	6.37	6.20	5.40	5.25

Adapted from: Fertilizer management for forage crops in central Alberta (Research Branch Technical Bulletin 1993-3E)

In a long term experiment where ammonium nitrate was annually applied over a 16-year period, N fertilizer had a marked effect on soil acidification (Table 2.4). Electrical conductivity (EC) is a measure of soil salinity. Salinity is known to be generally related to the downslope movement and discharge of soil water containing dissolved salts. Salinity will restrict growth of many crops due to its osmotic effect on holding back water from the plants (Larney et al., 1994). Salinity may restrict the activity of soil microorganisms, which in turn will affect the turnover of elements such as C and N (Campbell, 1978). Forage crops are grown on salt-affected land on the prairies to lower the water table and reduce salt movement upward with capillary rise of water and discharge (Henry et al., 1987).

2.5 Production of carbon dioxide and nitrous oxide gases

The composition of soil air depends on the relative intensity of sources and sinks for the various gas components, exchange between soil air and atmospheric air, and the partitioning of the gases between the gaseous, liquid, and solid phases of the soil (Farrell et al., 2002). The concentration of CO_2 has an effect on soil pH, especially in calcareous soils (Buyanovsky, 1972).

Soil is also the major source and potential sink for greenhouse gases including CO_2, N_2O, and CH_4 (Duxbury et al., 1993). These gases are produced near the soil surface as well as in underlying soil horizons and parent material, extending to and including ground water (Rice and Rodgers, 1993).

2.5.1 Carbon dioxide

Soils are the largest reservoirs of carbon (C) in the agricultural ecosystem. Release of CO_2 from soil to the atmosphere is an important part of C cycling in nature and provides a useful index for the effects of management on the C budget of an agricultural production system (Aslam et al., 2000). Agriculture contributes to the release of CO_2 through the oxidation of soil organic matter (SOM), especially with continuous tillage and high soil disturbance. Studies have indicated that losses of organic C to the atmosphere as CO_2 are most rapid when soils are first converted from grassland or forest to cultivated land (Mensah et al., 2003).

The activities of soil organisms and root respiration are important sources of C emission from the soil. The major sources of CO_2 associated with soil respiration, are live root respiration, microbal decomposition of dead roots and soil humus, along with aboveground residue decomposition. These sources influence the dynamics and seasonal patterns of CO_2 evolution from the soil and the distribution of residual C in an ecosystem. Buyanovsky et al. (1987) noted that in a multispecies grass stand dominated by slow-growing perennials with extended activity, less CO_2 was evolved than winter wheat, due to both autotrophic and heterotrophic competitive activities for most of the year. Davidson et al. (2000) observed that annual CO_2 emissions were lower from pasture soils (10–15 Mg C ha^{-1} yr^{-1}) than from forest soils (18–20 Mg C ha^{-1} yr^{-1}) in the eastern Amazon. Unfortunately, there is lack of CO_2 measurement data for grassland soil in temperate regions.

2.5.2 Nitrous oxide

Nitrous oxide (N_2O) is a greenhouse gas with important impacts on our environment. Its global warming potential is about 320 times as strong as that of CO_2 (Wrage et al., 2001), with a lifetime of approximately 120 years in the atmosphere (U.S.EPA, 2006). Nitrous oxide is emitted into the atmosphere as a result of biomass burning, and biological processes in soils. Biomass burning is not only an instantaneous source of nitrous oxide, but it results in a longer term enhancement of the biogenic production of this gas (Freney, 1997). Considerable anthropogenic emissions of N_2O arise from agricultural soil. In 1997, the largest single source of N_2O globally was reported to be the use of N fertilizers in agriculture (Wrage et al, 2001). From the study of Corre et al (1999) conducted in transitional grassland-forest region in Saskatchewan, Canada the average annual N_2O fluxes were higher in fertilized cropland, than pasture/hay land and forest areas (Table 2.5).

Table 2.5. Annual nitrous oxide emissions in different land use systems in Saskatchewan, Canada.

Area	Crop land	Pasture/hay land	Forest
		kg N_2O ha^{-1} yr^{-1}	
Emissions	2.00	0.04	0.02

Adapted from Corre et al (1999)

On a clay loam, cropped site, 2% and 3% of the applied N fertilizer was emitted as N_2O on the shoulders and footslopes respectively (Corre et al., 1999). Nitrous oxide production is controlled by temperature, pH, water holding capacity of the soil, irrigation practices, fertilizer rate, tillage practice, soil type, oxygen concentration, availability of carbon, vegetation, land use practices and use of chemicals (Freney, 1997). In a study by Eichner (1990) and Mosier et al. (1991), N fertilization and ammonium containing fertilizer increased N_2O emissions from grassland soils. Another study conducted by Clayton et al. (1997) found that the annual N_2O fluxes in grassland soil ranged from 0.2 to 2.2 % of the N applied, which was in the range of the present international estimate (1.25 ± 1.0 %) used for N_2O emission estimation from applied N. Soussana et al. (2007) noted that N_2O evolution was four times more in fertilized (175 kg N ha^{-1}) than unfertilized grassland at Laqueuille, France.

2.5.3 Methane

One of the contributors to global warming is the greenhouse gas methane. Soils can act as both a source and a sink of CH_4 (Nelson, 2002). Methanogenic bacteria are strict anaerobic bacteria that produce CH_4 as an end product of their energy pathways. Methane release is greatest in poorly drained soils (Frederick et al., 2005) and produced by the anaerobic reduction of CO_2, acetate, methanol, formate, carbon monoxide, methylated amines and dimethyl sulphide by methanogenic bacteria (Tyler, 1991). Groundwater and soil moisture are important factors controlling CH_4 emission and Moore and Roulet (1995) found that emissions were greater from falling water tables than rising ones. Temperature is another factor that is positively correlated to the flux of CH_4 (Rask et al., 2002). Research conducted by Soussana et al. (2007) in Laqueuille, France, showed that methane emission from fertilized (175 kg N ha^{-1}) grassland was 79 g m^{-2} $year^{-1}$ (CO_2-C equivalent), when unfertilized grassland produced 43 g m^{-2} $year^{-1}$ (CO_2-C equivalent) where mean annual rainfall was 1313 mm.

3.0 Plant and Soil Responses to Nitrogen and Phosphorus Fertilization in Saskatchewan, Canada and Selenge, Mongolia: Field Experiments

3.1 Introduction

Forages are the cheapest source of feed for livestock and there is potential to increase forage production through fertilization. N is the most commonly deficient essential nutrient in soil and generally has the greatest impact on forage production (Malhi et al., 2004), but P also may be limiting in some soils (Sedivec and Manske, 1990; Berg and Sims, 1995). Forage N concentration, N uptake also increase with N rate (Malhi et al., 1986; Ukrainetz and Campbell, 1988). The effectiveness of fertilizers in increasing forage dry matter yield (DMY) and economic return is dependent upon the levels of nutrients in the soil, moisture conditions, source, rate and method of fertilizer application, soil type and forage species. The amount and quality of forage production can have direct effects on animal performance. Fertilizer applications to perennial forage pastures have resulted in substantial increases in animal gain and carrying capacity compared to the pastures that receive no fertilizer (Agriculture and Agri-Food Canada,1993). This section of the thesis addresses the effect of N and P fertilization rate and application methods on the forage dry matter yield (DMY) and nutrient uptake and concentrations, residual nutrients, soil organic carbon (SOC), particulate organic matter (POM), pH and salinity.

3.2 Study Area Descriptions

The fertilization trials in Saskatchewan were started in the spring of 2005. All forage stands at the three sites in Saskatchewan were established between 1997 and 1999. The Baruunkharaa site in Mongolia was native rangeland. All sites had no history of fertilization at, or subsequent to, establishment.

3.2.1. Colonsay site

The Colonsay site was located near Colonsay, Saskatchewan, approximately 30 km east of Saskatoon (Figure 3.1) (legal location: NW 11-26-28 W2) (Owner of hayland is Ken Nowaselski). The soil at the site was a Dark Brown Chernozem of sandy loam texture and classified as Biggar soil association. The forage at the site was a meadow bromegrass dominated hayland, with about 10% alfalfa and 90% meadow brome composition of the stand, with relatively few weeds.

Figure 3. 1. Colonsay site receiving fertilizer application in spring of 2005

3.2.2 Vanscoy site

The Vanscoy site was located near Vanscoy, Saskatchewan, approximately 20 km southwest of Saskatoon (Figure 3.2) (legal location: NW 6-35-7 W3). The stand was mixed grass-alfalfa dominated by meadow bromegrass with less than 10% alfalfa. Soil at the Vanscoy site was a Dark Brown Chernozem of loamy sand texture (Owner of hayland is J. Wright). The site is mapped as Asquith soil association (Figure 3.2).

Figure 3. 2. Forage grass at the Vanscoy site following fertilizer application in June of 2005

3.2.3 Rosthern site

Figure 3. 3 Rosthern site in the summer of 2005

The Rosthern site was located near Rosthern, Saskatchewan, approximately 5 km north of the Seager Wheeler farm (legal location: SW 3-43-2 W3) (Owner, of hayland is R. Gauthier). Soil at the Rosthern site was a Black Chernozem of a sandy loam texture, mapped as the Meota soil association. Unlike the other sites, this site was a pure meadow bromegrass hayland (Figure 3.3).

3.2.4 Baruunkharaa site

The fourth site was located in Mongolia and the fertilizer trial was conducted only in spring of 2006. The forage cover at the site is a degraded and overgrazed natural pasture (State pastureland). The site was located near Baruunkharaa Soum, about 150 km north of the capital city Ulaanbaatar, Mongolia (Trans Mongolian highway Ulaanbaatar-Darkhan 151 km). The forage composition at the site was typical of mountain-steppe species (Festuca -15%, Agropyron -20%, Alliums -10%, Broadleaf -50%). The soil at the Baruunkharaa site is a Calcic Kastanozem (by FAO classification) with sandy loam texture. Slopes dominantly range from 2 to 5% that produce hummocky, inclined landforms (Figure 3.4).

Figure 3. 4 Baruunkharaa site in the spring of 2006

3.3 Experimental Design and Treatments

The fertilizer experiments in Saskatchewan were established in spring of 2005, and in the spring of 2006 in Mongolia. The experimental design was a randomized complete block design (Figure 3.5).

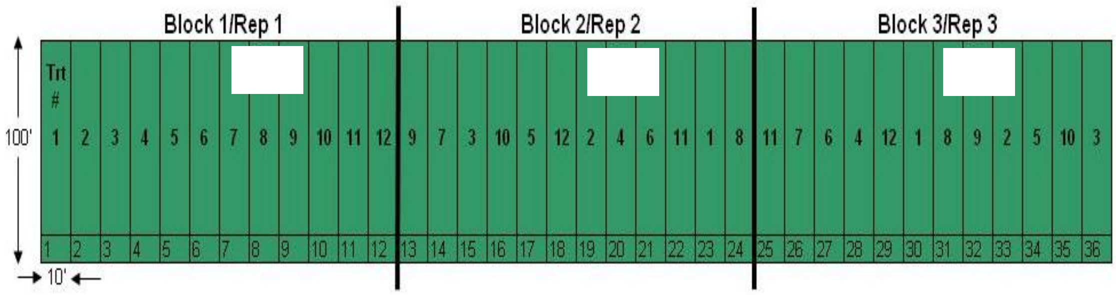


Figure 3. 5 Plot diagram

Treatment for Saskatchewan sites:

1. Coulter Control-No Fertilizer (Coulter Inserted)
2. 56 kg N and 28 kg P_2O_5 ha^{-1} Blend Coulter Injected
3. 112 kg N and 28 kg P_2O_5 ha^{-1} Blend Coulter Injected
4. Dribble Control-No fertilizer
5. 56 kg N and 28 kg P_2O_5 ha^{-1} Blend Dribble Banded
6. 112 kg N and 28 kg P_2O_5 ha^{-1} Blend Dribble Banded
7. 56 kg N ha^{-1} Dribble Banded (no P_2O_5)
8. 112 kg N ha^{-1} Dribble Banded (no P_2O_5)
9. 224 kg N ha^{-1} Dribble Banded (no P_2O_5)
10. 56 kg N ha^{-1} Coulter Injected (no P_2O_5)
11. 112 kg N ha^{-1} Coulter Injected (no P_2O_5)
12. 224 kg N ha^{-1} Coulter Injected (no P_2O_5)

Saskatchewan sites: The forage fertilization experiment in Saskatchewan involved six fertilizer rate treatments: 1) Control-No fertilizer; 2) 56 kg N ha^{-1}; 3) 56 kg N and 28 kg P_2O_5 ha^{-1}; 4) 112 kg N ha^{-1}; 5) 112 kg N and 28 kg P_2O_5 ha^{-1}; 6) 224 kg N ha^{-1} (Figure 3.5). The fertilizers were applied as solution N and P fertilizers (28-0-0 and 10-34-0) using two different application methods: 1) dribble banded in which fertilizer was surface - applied as a dribble band, and 2) coulter injected with a coulter disc placing the fertilizer directly in the soil as a band (Figure 2.3). The fertilizer was applied in the third week of April in 2005. The coulter injection and dribble banded treatments applied the liquid fertilizer at about 5 cm depth, in bands 30 cm apart. In total, there are 12 treatments and each treatment was replicated three times. Therefore, each site has a total of 36 experimental plots, each 3 m x 30 m.

Mongolia site: The treatments were: 1) Control-No fertilizer; 2) 50 kg N ha^{-1}; 3) 50 kg N and 25 kg P_2O_5 ha^{-1}; 4) 100 kg N ha^{-1}; 5) 100 kg N and 25 kg P_2O_5 ha^{-1}; 6) 200 kg N ha^{-1}. The fertilizer was applied on May 10, 2006. The fertilizer form at the Mongolian site was granular, as liquid sources were not available. Ammonium nitrate (34-0-0) and triple super phosphate (0-40-0) fertilizers were applied using two different application methods: 1) surface banded in which granular fertilizer was dribbled onto the surface in a band and; 2) knife inserted with a narrow opener placing the fertilizer directly in the soil as a band. The knife was inserted at a 5 cm depth, and the spacing between knife or dribble was 23 cm. There were 12 treatments, with three replicates. The site had 36 experimental plots, each 3 x 30 m.

3.4 Soil Sampling and Analysis

Soil samples were taken from the centre of the plots of the control treatments to characterize the sites. Using a truck equipped with a hydraulic punch, in each plot three cores were taken to a 60 cm depth with the cores segmented into three depth increments (0 to 15; 15 to 30; 30 to 60 cm) for soil nutrient and carbon content. The cores were placed in plastic bags and put in an insulated container, and stored at 4ºC until further processing was done. In the fall of 2005, in each plot at all Saskatchewan sites a PVC pipe of 10 cm diameter, and 15 cm length was forced down to a depth of 15 cm to remove a core of 0-15 cm. One core was taken from each plot. The cores were put in plastic bags and placed in an insulated container and stored at 4ºC. Prior to processing the cores for their static properties (organic C, EC, pH, extractable nutrients), the cores were subjected to a two week incubation at field moisture content, as described in Section 4, to measure CO_2 and N_2O evolution and nutrient supply rate using PRS™ probe. When it came time to process the cores for their static properties, they were air dried before being ground to pass through a 2 mm sieve.

Cores segmented into 0 to 15, 15 to 30 and 30 to 60 cm depths were taken in the spring of 2006 to measure residual N.

3.4.1 Organic carbon

Soil organic carbon was determined using a LECO CR-12 Carbon Analyzer (Wang and Anderson, 1998). The soil preparation for use in the Carbon Analyser first involved grinding the soil to pass through a 40 mesh sieve. A 0.15 g sub-sample was then placed into the furnace at a set temperature of 840º C. The soil organic carbon was oxidized to CO_2 which was then measured by an infrared (IR) cell (Leco, 1987). In order to prevent drift the IR cell was calibrated with a known carbon sample (sucrose). To ensure that only organic carbon is was measured care was also taken to remove the sample from the furnace after 120 seconds as inorganic carbon begins to decompose after 150 seconds.

3.4.2 Particulate organic matter

Particulate organic matter is considered recent, it formed easily oxidizable organic material in soils, changes in which have been proposed as an early indicator of SOC changes (Hussain et al., 1999). Particulate organic matter was measured in the surface (0-5 cm) depth increment, as POM at the surface is the fraction most sensitive to management of organic matter (Hussain et al., 1999). Particulate (>53μm) and mineral-associated organic matter (<53 μm) were separated from each aggregate size fraction by sieving after mechanical dispersion of the soil by agitation in water with glass beads according to the procedure outlined by Balesdent et al. (1991) as cited in Aoyama et al. (1999). In this method aggregate size fractions of less than 2 mm were subsampled (5 g) and placed in a 125 mL Erlenmeyer flask. The soil in the flask was shaken with 50 mL deionized water and five glass beads (6 mm in diameter) for 16 hr on a reciprocal shaker. The dispersed particulate organic matter plus sand were collected on the surface of a 53-µm sieve and washed with 340mL deionized water from a squeezable water dispenser. The material >53 µm was dried in a forced-air oven at 40ºC and weighed. The mass of particles in the aggregate size fractions was determined by the difference between the mass of undispersed particulate (> 53 µm) aggregates and that of the material in the <53 µm size fraction. The contents of total C in the fractions were directly determined by the LECO CR-12 Carbon Analyzer (Wang and Anderson, 1998).

3.4.3 Electrical conductivity (EC) and pH

The procedure for determining the electrical conductivity (EC) and pH followed the technique of Hendershot and Lalande (1993) and Janzen (1993) respectively. Twenty g of soil was weighed into a plastic bottle and 40 mL of distilled water was added. The bottles were placed on a rotary shaker at 142 revolutions per minute (RPM) for 20 minutes, then left to stand for two hours. The resulting 2:1 distilled water to soil suspension was filtered through a Whatman No. 1 filter. The filtrate was analyzed for pH and EC with a Beckman 50 meter for pH and a Horiba ES-12 conductivity meter for EC.

3.4.4 Soil extractable nutrients

The KCl extraction to measure NO_3-N and NH_4- N was carried out according to Keeney and Nelson (1982). Five grams of soil was weighed out into extraction bottles, and 50 mL of 2M KCl solution added. The bottles were then shaken on a rotary shaker for 1 hour at 142 RPM. The solution was then filtered through a Whatman® 454 filter paper into vials. The vials were capped and stored at 4ºC until they were analyzed using a Technicon™ Auto-analyzer sampler II; AAII single channel colorimeter with 1.5 (id) x 30 mm tubular flowcell, 420 nm interference filter, and voltage stabilizer and recorder (Technicon Industrial Systems, Tarrytown, NY 10591)

A Modified Kelowna (MK) extraction was used to determine extractable P and K according to the procedure outlined by Qian et al. (1994a). The extractant solution was prepared by mixing 0.25M HOAc, 0.25M NH_4OAc, and 0.015M NH_4F with a measured pH of 4.9. A known weight of soil (3 g) was placed into 100 mL plastic extraction bottles with 30 mL of the MK extractant solution, then shaken on a rotary shaker at 200 RPM for 5 min. The mixture was then filtered using a Whatman® #454 filter paper into plastic vials and the extractant stored at 4º C until the samples were able to be colorimetrically analyzed using the Technicon™ Auto-analyzer sampler II.

3.5 Plant Sampling and Analysis

3.5.1 Dry matter yield

Above ground forage dry matter yield measurements were made in Saskatchewan in the summer of 2005 and 2006, between June 30 and July 8 each year. The Mongolian sampling was done on August 5, 2006, because of cold weather conditions in the spring that delayed growth. Sampling of each plot was conducted by taking three subsamples using a 0.25 m^2 quadrat (50 x 50 cm) at randomly selected points. Plants were cut level with the ground to simulate a mower and placed in cotton bags and air-dried at 30^o C in a forced airbox for 5 days, then weighed to obtain biomass yields. The plant material was run through a Wiley plant grinding machine and a representative 30g subsample kept for determine plant nutrient uptake.

3.5.2 Total N and P

Total N and P concentrations in the plant were determined on dried, ground sample using a standard H_2SO_4-H_2O_2 digestion method (Thomas et al., 1967). This procedure involved taking a ground plant sample of 0.25 g and placing it in a 75 mL digestion tube and then adding 5 mL of concentrated sulphuric acid. The mixture was then mixed vigorously on a vortex shaker and placed in a block digester at 360º C for 20 min. Then 0.5 mL of 30% (vol vol^{-1}) H_2O_2 was added to the tubes, which were vortexed a second time and heated at 360º C for another 30 min. The tubes were then removed, cooled and an additional 0.5 mL H_2O_2 were added to the tubes. This heating and cooling procedure was repeated five more times. The last heating procedure involved a one-hour heat treatment instead of a 30 min treatment to completely remove the last remaining H_2O_2 from the sample. When the 30 min cooling had taken place, the remaining sample was brought up to volume (75 mL) with deionized water. The samples were shaken and transferred into 50 mL plastic vials for storage and further analysis. Total P and N concentrations were determined colorimetrically as phosphate and ammonium in the digest solution using the Technicon™ Auto-analyzer (Tarrytown, NY). Total plant nutrient uptake was determined by multiplying the dry matter nutrient concentrations by yield.

3.6 Statistical analysis

This experiment was set up as a randomized complete block design. A significant ANOVA result indicates that at least one of the mean treatments was different (Zar, 1999). Mean separation was done using least significant difference (LSD) at an $\alpha = 0.05$ unless otherwise stated (SPSS, 2005).

3.7 Results and Discussion

3.7.1 Meteorological data and basic soil properties

Weather data from Saskatoon (central to all three sites), showed that the mean monthly temperatures for April were warmer than the long-term average. The temperatures at the Mongolia site were below the long-term averages (April and May of 2006). May, June, July and August temperatures were below average in 2005 and close to or slightly higher than the long-term average in 2006 at all four sites. In 2005 and 2006 at all three Saskatchewan sites, spring (April-June) precipitation was above the long-term average. Precipitation in June was nearly double the long-term average, whereas July and August totals were below or near the long-term average. Total annual precipitation at all three Canadian sites during 2005 and 2006 was above the long-term average.

Table. 3.1. General weather data of 2005 and 2006 at three Saskatchewan sites and Baruunkharaa site in Mongolia.

	Months					
	April	May	June	July	August	September
Saskatchewan (Saskatoon)						
Years	Daily average temperature (^oC)					
2005	6.4	10.2	14.4	17.5	15.4	11.3
2006	8.0	11.7	16.2	20.0	18.0	M†
30 Year average	4.4	11.5	16.0	18.2	17.3	11.2
	Precipitation (mm)					
2005	15.5	27.5	160.5	53.5	53.5	74.0
2006	38.0	39.9	108.0	32.0	30.0	M
30 Year average	23.9	49.4	61.1	60.1	38.8	30.7
Mongolia (Baruunkharaa)						
	Daily average temperature (^oC)					
2006	-6.0	3.7	17.0	19.5	18.0	11.2
30 Year average	2.7	10.7	16.5	18.5	16.5	9.4
	Precipitation (mm)					
2006	6.4	63.6	51.8	55.9	24.3	24.3
30 Year average	9.1	19.4	55.7	82.8	74.4	35.9

†- Data is missing.

Source: Environment Canada and Meteorological Centre of Mongolia. 2006

Table 3.2. Basic soil properties of the three Saskatchewan sites.

	Sites		
	Colonsay	*Vanscoy*	*Rosthern*
Available NO_3, μg g^{-1}	0.65	0.75	0.30
Available NH_4, μg g^{-1}	0.67	0.38	0.23
Available P, μg g^{-1}	2.81	1.45	5.66
Available K, μg g^{-1}	164.32	61.82	62.52
Mean pH	7.34	7.43	7.30
EC, dS/m	0.25	0.11	0.08
Organic Carbon, %	1.26	1.27	1.06

The Mongolia site received precipitation amounts that were below the long-term average for April to September but with greater than average precipitation in May.

Soil basic properties of the three Saskatchewan sites showed deficient amount of nutrients are available for the plants (Table 3.2).

3.7.2 Forage dry matter yield response

All fertilization treatments produced significantly (*$p<0.05$*) (Tables 3.3 and 3.4) higher yield than the control in the year of application. The dry matter yield response to fertilization varied among sites, with less response in the native rangeland in Mongolia (Table 3.4) than in the tame grass haylands in Saskatchewan. There were no significant differences in yield between application methods except in the 224 kg N ha^{-1} treatment at Vanscoy in 2005, where dribble banded was higher than coulter injected. In all cases at the Saskatchewan sites, in the second year following fertilization the DMY in fertilized treatments was lower than in first year and not significantly different than the 2006 control except the high rate treatments (224 kg N ha^{-1}). At this rate, there was a sufficient amount of residual N to produce a significant yield increase over the control in year 2. At Rosthern the biomass yield in year two (2006) was not significantly different than year 1 (2005). The findings are similar to the findings of Misselbrook et al. (1996) who reported on a study of injection of slurry fertilizer (80 kg N ha^{-1}) on a ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) sward and Lardner (1998) who injected liquid fertilizer (100 kg N, 45 kg P_2O_5, 23 kg K_2O, and 12 kg S ha^{-1}) into a 20-year old pasture with smooth bromegrass (*Bromus Inermis* Leyss.) and alfalfa (*Medicago sativa* L.) at Pathlow, Saskatchewan. Both these studies showed lower yields in the second year after application as the applied N was utilized by the crop in the first year (Lardner, 1998; Malhi et al., 2004). In the current study, a carryover effect of the N fertilizer was observed on the 224 kg N ha^{-1} treatment plots in the three Saskatchewan sites, and for the 112 kg N ha^{-1} treatment at Rosthern, in 2006. High rates of N fertilizer in excess of crop requirement in the year of application can effectively carryover and supply N to the forage in the following year, although possible loses by denitrification or leaching must be considered.

Table 3.3. Dry matter yield (kg ha^{-1}) at the three Saskatchewan sites in 2005 and 2006.

	2005			2006		
	Colonsay	*Vanscoy*	*Rosthern*	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate	kg ha^{-1}					
	Dribble Banded					
Control- No Fertilizer	3029	2046	1946	2578	2103	1889
56 kg N & 28 kg P	4749*	4243*	4502*	2561	1754	2154
112 kg N & 28 kg P	4949*	5002*	4735*	2753	2336	2468
56 kg N	4643*	4446*	4183*	2369	1991	1986
112 kg N	4552*	4959*	4458*	2549	2240	3261*
224 kg N	5081*	5400*	4578*	4096*	2686*	4402*
	Coulter Injected					
Control- No Fertilizer	2777	2358	2634	1844	1854	2176
56 kg N & 28 kg P	4707*	3723*	3984*	2727*	1932	2544
112 kg N & 28 kg P	5366*	4823*	4600*	2704*	1870	2327
56 kg N	3835*	4026*	4274*	2890*	1970	1936
112 kg N	3946*	5150*	4602*	2825*	2222	3150*
224 kg N	4658*	4239*	4339*	3534*	2706*	4315*
LSD $_{(0.05)}$	**842**	**818**	**1048**	**568**	**532**	**777**

* Significantly different than the control for same application method at the 0.05 probability level

At Baruunkharaa in 2006, DMY increases over the control were observed for all fertilized treatments (Table 3.4). The response was similar to that reported in the study of Badam (1961) and Jigjidsuren (1974) who found an increase in DMY, from applied N fertilizer on native rangeland in Mongolia.

Many researchers have indicated that N is the major limiting nutrient in grass dominated pastures and haylands (Malhi et al., 2004; Theaker et al., 1994; Chen et al., 2004). The higher DMY because of response to N fertilization observed in this study is similar to the findings in Brown and Dark Brown soils in Saskatchewan (Campbell et al., 1986) and Black soils in Alberta (Malhi et al., 1993). The addition of 28 kg P_2O_5 ha^{-1} P fertilizer with the N fertilizer did not increase yield, with the exception of the Colonsay site, where the coulter injected treatment increased the yield.

Table 3.4. Dry matter yield (kg ha^{-1}) at Baruunkharaa site in 2006 ($LSD_{(0.05)}$ = 406)

Fertilizer application method and rate	kg ha^{-1} Dribble Banded	kg ha^{-1} Knife Inserted
Control- No Fertilizer	1277	1281
50 kg N & 25 kg P	1832*	1891*
100 kg N & 25 kg P	2043*	1852*
50 kg N	1705*	1771*
100 kg N	1965*	1828*
200 kg N	2094*	2008*

* Significantly different than the control for same application method at the 0.05 probability level

Harapiak et al. (1984) also reported that grass dominated haylands are much less responsive to P fertilizer than N. This may be due to mineralization of organic P in the rhizosphere of grasses and/or a significant role of arbuscular mycorrhizal fungi in enhancing P turnover and availability. The study indicated a trend for increased production in the year of application with increasing fertilizer N application rates, as the meadow bromegrass tended to have higher yield at rates of 112 kg N ha^{-1} and 224 kg N ha^{-1} than 56 kg N ha^{-1} fertilizer treatments. The same trend was evident with the Mongolian site. However in many cases, the DMY at N rates above 50 kg N ha^{-1} was not significantly different from the 50 kg ha^{-1} rate. It would appear that close to maximum yield could be achieved by application of ~50 kg N ha^{-1} according to the results of this study.

3.7.3 Forage N and P uptake

Total plant uptake of N and P (yield x N and P concentration) generally followed the same pattern as yields. In year 2005 the N and P uptake in the fertilized treatments was higher than the control at the all sites (Table 3.5) except the P uptake in the 112 kg N ha^{-1} dribble banded treatment at Colonsay site, and the 56 kg N ha^{-1} and 224 kg N ha^{-1} coulter injected treatment at Vanscoy. Good weather condition with sufficient precipitation for good growth and nutrient demand would promote forage N and P uptake with fertilization. The N uptake at the three sites increased with increasing rate up to the highest rate of 224 kg N ha^{-1}, including rates above which yield was maximized. Therefore it appears that much of the additional N uptake at the high rates is contributing to protein.

Table 3.5. Forage N and P uptake in 2005 at the three Saskatchewan sites

Sites	*Colonsay*		*Vanscoy*		*Rosthern*	
	N †	P†	N	P	N	P
Treatment + Fertilizer application method and rate			kg ha^{-1}			
			Dribble Banded			
Control- No Fertilizer	42.4	4.7	21.4	2.1	18.7	3.7
56 kg N & 28 kg P	82.9*	8.5*	60.2*	5.6*	59.8*	8.5*
112 kg N & 28 kg P	105.4*	8.9*	92.7*	9.1*	71.6*	9.9*
56 kg N	92.0*	7.9*	66.4*	4.9*	54.1*	7.7*
112 kg N	98.8*	5.8	87.3*	5.6*	70.3*	8.4*
224 kg N	126.8*	7.2*	130.2*	6.5*	88.5*	8.6*
			Coulter Injected			
Control- No Fertilizer	34.2	3.5	25.2	3.2	28.8	5.2
56 kg N & 28 kg P	84.4*	8.5*	54.6*	5.1*	53.6*	8.0*
112 kg N & 28 kg P	116.6*	10.6*	78.3*	6.7*	72.2*	8.8*
56 kg N	73.2*	5.1	50.9*	4.0	56.2*	7.9*
112 kg N	91.5*	5.9*	87.3*	5.4*	61.8*	7.9*
224 kg N	124.8*	7.7*	88.6*	4.1	97.4*	9.3*
LSD $_{(0.05)}$	**18.9**	**2.1**	**21.5**	**1.7**	**20.5**	**2.4**

* Significantly different than control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

In a study conducted by Lutwick and Smith (1979), bromegrass N uptake increased with an associated increase in yield and protein production with N fertilizer application. They observed that N uptake was greater in wet years (1967 and 1969) than in dry years (1970). The P uptake also increased with N fertilizer addition, reflecting greater demand for other nutrients when a N limitation is overcome. The P fertilization with 28 kg P_2O_5 ha^{-1} also increased P uptake over the equivalent rate of N with no P fertilizer.

P fertilization increased P uptake at Colonsay, Vanscoy, and Rosthern. The additional P uptake was not associated with a yield response to P at any of the sites. Kilcher (1958) also reported that a grass stand in southern Saskatchewan was not responsive to P, but there was a higher P uptake associated with the general yield response to increasing amounts of N. The site in Mongolia (Table 3.7) showed less effect of fertilization on N and P uptake than the three Saskatchewan sites. There was a significant response to N fertilization on N uptake, but no effect of P fertilization. The P uptake increased at the highest N rate. Overall, the native range species at the Mongolia site removed much less N and P than the meadow bromegrass at the Saskatchewan sites.

In the year after fertilization, 2006, the forage P uptake (Table 3.6) did not show any significant differences between treatments except at Rosthern where P uptake was increased at the highest N application rate, consistent with the higher yield from carryover of N and subsequent increased demand for P. However N uptake in the 224 kg N ha^{-1} treatment at all sites and the 112 kg N ha^{-1} treatment at the Rosthern and Colonsay sites, and the 56 kg N ha^{-1} treatment at the Colonsay site were significantly higher than the control. Lutwick and Smith (1979) also found that only very high rates of N (254, 354 kg ha^{-1}) produced a long-term effect, lasting two or three years.

Table 3.6. Forage N and P uptake in 2006 at the three Saskatchewan sites

Sites	*Colonsay*		*Vanscoy*		*Rosthern*	
	N	P	N	P	N	P
Treatment + Fertilizer application method and rate	kg ha^{-1}					
	Dribble Banded					
Control- No Fertilizer	36.5	4.2	26.0	3.4	17.9	3.8
56 kg N & 28 kg P	33.4	4.3	22.3	3.3	21.3	3.9
112 kg N & 28 kg P	32.0	4.6	29.5	3.9	23.8	4.5
56 kg N	32.4	3.9	26.1	3.0	19.0	3.5
112 kg N	32.5	3.7	26.8	3.2	32.4*	5.6*
224 kg N	54.9*	4.6	45.2*	3.2	51.7*	7.5*
	Coulter Injected					
Control- No Fertilizer	23.4	3.3	21.6	3.1	21.6	4.4
56 kg N & 28 kg P	30.3	4.4	27.2	3.0	26.1	4.6
112 kg N & 28 kg P	32.8	4.3	23.9	3.1	22.9	4.2
56 kg N	32.9*	4.0	25.2	3.0	18.4	3.4
112 kg N	38.9*	4.0	28.8	3.3	30.7*	5.5
224 kg N	54.6*	4.5	35.4*	3.2	50.6*	7.5*
LSD $_{(0.05)}$	**9.3**	**1.3**	**7.9**	**0.8**	**7.1**	**1.5**

* Significantly different from control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

Table 3.7. Forage N and P uptake in 2006 at the Mongolian site (Baruunkharaa)

Uptake †	N		P	
	kg ha^{-1}			
Fertilizer application method and rate ‡	DB	KI	DB	KI
Control	14.4	14.2	1.3	1.2
50 kg N & 25 kg P	23.1*	20.2	1.7	1.9
100 kg N & 25 kg P	24.7*	19.7	1.9	2.0
50 kg N	22.8*	20.2	1.8	1.6
100 kg N	23.2*	18.7	1.7	2.0
200 kg N	26.0*	20.9	1.9	2.6*
$LSD_{(0.05)}$	**6.7**		**0.75**	

* Significantly different from control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

‡ DB - Dribble Banded; KI- Knife Inserted

Brown et al. (2000) report that N uptake by perennial grass averaged over two years was 165 kg N ha^{-1} when 200 kg N ha^{-1} was applied. These findings are similar to the current study, where N uptake by meadow bromegrass was 180 kg N ha^{-1} over two years when applied at a rate of 224 kg N ha^{-1} at the beginning of the first year at the Colonsay site.

3.7.4 N concentration in forage

The N concentration in the forage was increased (significantly *$p \leq 0.05$*) at the Colonsay, Vanscoy and Rosthern sites in 2005 by applying N fertilizer (Table 3.8). The concentrations increased with increasing N application rate. The N concentration values ranged from 12.3- 26.7 g kg^{-1} at Colonsay; 10.8-24.0 g kg^{-1} at Vanscoy; and 9.6-22.4 g kg^{-1} at the Rosthern site.

Campbell et al (1986) noted that when N was applied in a single application at Swift Current, Saskatchewan, the N concentration in forage grass was significantly ($p \leq 0.05$) increased at all rates (50, 100 and 200 kg N ha^{-1}) and in all years (1976, 1979-1981) except in a very dry year (1980) when lack of moisture probably limited N uptake. However, the N concentration not increased at the Mongolian site (Table 3.9).

Table 3.8. N concentration in dry matter in 2005 at the three Saskatchewan sites

	Colonsay	Vanscoy	Rosthern
		g kg^{-1}	
Fertilizer application method and rate		Drrible Banded	
Control- No Fertilizer	12.3	10.8	10.9
56 kg N & 28 kg P	18.0*	14.6*	13.5*
112 kg N & kg 28	22.0*	16.3*	15.7*
56 kg N	19.0*	12.6	13.0*
112 kg N	23.2*	17.1*	13.4*
224 kg N	26.7*	21.1*	22.4*
		Coulter Injected	
Control- No Fertilizer	14.0	10.8	9.6
56 kg N & 28 kg P	17.5*	14.1	13.3*
112 kg N & kg 28	21.2*	18.5*	15.2*
56 kg N	19.8*	14.9*	12.9*
112 kg N	21.9*	17.3*	15.9*
224 kg N	25.1*	24.0*	19.3*
LSD (0.05)	**3.3**	**3.3**	**2.2**

** Significantly higher than control at the 0.05 probability level than control*

Table 3.9. N concentration in DMY in 2006 at Mongolia site ($LSD_{0.05}$=3.3)

	g kg^{-1}	
Fertilizer application method and rate	Dribble Banded	Knife inserted
Control- No Fertilizer	11.4	11.2
50 kg N & 25 kg P	12.0	12.7
100 kg N & 25 kg P	12.4	10.6
50 kg N	10.6	10.6
100 kg N	12.4	11.0
200 kg N	10.9	12.5

The N concentration is used to estimate crude protein in plants, calculated by multiplying % N by 6.25 (Malhi and Ukrainetz, 1990). In 2005, the protein concentration in bromegrass increased with increasing rates of N and, in 2006, at the highest N rates at some sites. Protein concentration tended to be highest at Colonsay, possibly due to a greater proportion of alfalfa in the stand at this site. In a study by Malhi et al. (2002), found an increase in protein content of 3.6% when 60 kg N ha^{-1} was applied and 9.4% when at 180 kg N ha^{-1} was applied in spring on a smooth bromegrass stand in Lacombe, Alberta. In our study, we had a similar protein response with an increase in percentage of protein of 3.6% with 56 kg N ha^{-1} and 9.0 % with 224 kg N ha^{-1} at the Colonsay site in dribble banded fertilizer applications. At the Vanscoy and Rosthern sites, similar results were also obtained (Table 3.10).

There was a general trend of higher forage N concentration from the high rates of N fertilizer application treatments in 2006 (Table 3.11). This effect was also noted in several other studies where application of high rates (≥200 kg N ha^{-1}) of N fertilizer increased forage N concentration (Ukrainetz et al., 1988; Lardner, 1998). At N rates less than 100 kg ha^{-1} the response is observed for only one or two years (Read and Winkelman, 1982).

Table 3.10. Percentage of protein in forage dry matter

	2005			2006		
	Colonsay	Vanscoy	Rosthern	Colonsay	Vanscoy	Rosthern
			%			
Fertilizer application method and rate			Dribble Banded			
Control- No Fertilizer	7.7	6.8	6.8	8.2	7.3	6.2
56 kg N & 28 kg P	11.3*	9.2	8.4	8.1	8.8	6.4
112 kg N & 28 kg P	13.8*	10.2*	9.8*	8.4	8.0	6.2
56 kg N	11.9*	7.9	8.1	7.9	8.0	6.0
112 kg N	14.5*	10.7*	8.4	8.5	8.1	6.1
224 kg N	16.7*	13.2*	14.0*	9.3*	8.1	7.3
			Coulter injected			
Control- No Fertilizer	8.8	6.7	6.0	9.2	7.7	6.0
56 kg N & 28 kg P	10.9*	8.8	8.3	8.4	8.0	6.2
112 kg N & 28 kg P	13.3*	11.6*	9.5*	7.4	7.9	6.1
56 kg N	12.4*	9.3	8.1	8.7	8.3	6.0
112 kg N	13.7*	10.8*	9.9*	8.2	7.5	6.3
224 kg N	15.7*	15.0*	12.1*	9.6	10.6*	7.4*
LSD $_{(0.05)}$	**2.1**	**2.6**	**1.9**	**1.1**	**1.5**	**1.3**

** Significantly higher than control at the 0.05 probability level than control*

Overall, the highest N fertilization rates have significant effects on forage N concentration. However when a high rate of N is applied annually, nitrate toxicity in forages may become an issue, as high nitrates were observed in bromegrass that became a problem in later years as mineral N accumulated (Ukrainetz et al., 1988).

Table 3.11. N concentration in dry matter in 2006 at the three Saskatchewan sites

	Colonsay	Vanscoy	Rosthern
		—— $g\ kg^{-1}$ ——	
Fertilizer application method and rate		Drrible Banded	
Control- No Fertilizer	13.1	11.7	10.0
56 kg N & 28 kg P	13.0	14.1*	10.3
112 kg N & kg 28	13.4	12.8	10.0
56 kg N	12.6	12.8	9.5
112 kg N	13.5	13.0	9.8
224 kg N	14.9	13.0	11.7*
		Coulter Injected	
Control- No Fertilizer	14.8	12.3	9.6
56 kg N & 28 kg P	13.5	12.8	9.9
112 kg N & kg 28	11.9	12.6	9.7
56 kg N	14.0	13.2	9.6
112 kg N	13.1	12.0	10.0
224 kg N	15.3	16.9*	11.8*
LSD (0.05)	**2.3**	**2.2**	**1.0**

** Significantly higher than control at the 0.05 probability level than control*

3.7.5 Extractable soil nutrients

Due to time constraints, soils were not collected from the Mongolian site at the end of the 2006 season. Therefore the section on soil measurements is restricted to the three Saskatchewan sites.

3.7.5.1 Extractable ammonium and nitrate in fall of 2005

Only the 224 kg N ha^{-1} treatment at the Vanscoy and Rosthern sites showed a significant effect of fertilizer treatment on extractable ammonium (NH_4^+-N) in fall 2005 (Table 3.12), with mean ammonium concentrations (0-15 cm) that were significantly higher than the control for coulter injected. A similar treatment effect (Table 3.13) was observed for the nitrate (NO_3-N) concentrations, with significantly higher nitrate concentration only at the 224 kg N ha^{-1} rate for some sites and application methods. The elevation in soil available N observed at the end of the 2005 season at the highest N application rate likely was the main factor contributing to enhanced yield in these N rate treatments in 2006.

Table 3.12. Soil extractable ammonium (NH_4-N) in the 0-15 cm depth in fall of 2005

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		mg kg^{-1}	
		Dribble Banded	
Control- No Fertilizer	2.25	2.69	1.93
56 kg N & 28 kg P†	2.69	3.11	2.41
112 kg N & 28 kg P	2.14	2.70	2.12
56 kg N	3.54	4.09	2.15
112 kg N	3.69	5.34	3.43
224 kg N	1.89	3.36	2.29
		Coulter Injected	
Control- No Fertilizer	6.26	4.19	2.85
56 kg N & 28 kg P	3.74	4.59	2.85
112 kg N & 28 kg P	4.25	3.96	2.66
56 kg N	3.71	3.89	1.78
112 kg N	4.08	5.31	3.93
224 kg N	4.34	9.78*	11.56*
LSD $_{(0.05)}$	**2.76**	**1.96**	**2.79**

* Significantly different than control at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

Table 3.13. Soil extractable nitrate (NO_3-N) in the 0 to 15 cm depth in Fall of 2005.

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		mg kg^{-1}	
		Dribble Banded	
Control- No Fertilizer	7.86	11.97	3.68
56 kg N & 28 kg P†	6.05	7.17	3.54
112 kg N & 28 kg P	3.02	9.28	4.31
56 kg N	10.18	5.10	1.76
112 kg N	8.05	7.76	3.55
224 kg N	5.80	15.64	10.59*
		Coulter Injected	
Control- No Fertilizer	6.27	8.60	4.23
56 kg N & 28 kg P	8.38	7.69	2.98
112 kg N & 28 kg P	7.95	7.34	2.33
56 kg N	7.32	7.05	1.92
112 kg N	10.28	7.22	2.32
224 kg N	12.63*	12.20*	5.51
LSD $_{(0.05)}$	**4.25**	**5.09**	**2.45**

* Significantly different from control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

3.7.5.2 Extractable phosphorus (P) in fall of 2005

The Modified Kelowna (MK) extractable P concentrations did not show a treatment difference at any of the sites. The limited effect of the P fertilizer addition on extractable soil P may be explained by the greater P uptake and removal in

Table 3. 14. Soil extractable phosphorus in the 0-15 cm depth in fall of 2005

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		mg kg^{-1}	
		Dribble Banded	
Control- No Fertilizer	4.24	2.86	10.55
56 kg N & 28 kg P†	4.62	4.28	7.87
112 kg N & 28 kg P	3.91	3.35	7.20
56 kg N	4.22	2.89	10.46
112 kg N	3.22	2.77	9.33
224 kg N	2.60	3.25	8.53
		Coulter Injected	
Control- No Fertilizer	3.54	3.43	13.79
56 kg N & 28 kg P	4.75	3.94	8.79
112 kg N & 28 kg P	5.06	3.66	7.85
56 kg N	2.98	3.14	9.74
112 kg N	3.59	2.81	12.15
224 kg N	3.29	3.31	9.38
LSD $_{(0.05)}$	**2.27**	**1.30**	**6.52**

* Significantly different from the control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

response to N fertilization (Table 3.5), as well as entry of fertilizer P into soil P forms that the MK extraction does not remove, such as organic P.

3.7.5.3 Extractable Potassium in the 0-15 cm depth in fall of 2005

Control treatments had significantly higher extractable K than many of the N and P fertilized treatments, at Rosthern site (Table 3.15). This is likely due to increased K removal in yield responses to N application that resulted in increased K uptake from the soil. Perennial grasses are luxury consumers of K, and N fertilization of low K soils such as Rosthern (Table 3.2) will result in increased K uptake that decreases soil K (Cherney et al., 1998).

Table 3.15. Soil extractable potassium (K) from 0 to 15 cm depth in fall 2005 at three sites in Saskatchewan

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		mg kg^{-1}	
		Dribble Banded	
Control- No Fertilizer	395	197	207
56 kg N & 28 kg P†	325	190	140*
112 kg N & 28 kg P	388	194	159
56 kg N	390	154	155
112 kg N	318	168	159
224 kg N	257*	177	130*
		Coulter Injected	
Control- No Fertilizer	326	197	275
56 kg N & 28 kg P	310	189	142*
112 kg N & 28 kg P	297	176	148*
56 kg N	292	180	139*
112 kg N	332	181	137*
224 kg N	347	266*	155*
LSD $_{(0.05)}$	**128**	**59**	**53**

* Significantly different from the control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

The increase in extractable K at the high rate of N at Vanscoy is unexpected. It could be due to release of interlayer K from clay minerals induced by a high concentration of ammonium.

3.7.6 Residual nitrate in spring 2006

There were few significant differences in profile (0 to 60 cm) NO_3 concentrations in the spring of 2006 with the exception of some of the higher N fertilizer application rates where nitrate concentrations were elevated (Table 3.16). This is similar to the pattern in concentrations of NO_3-N in the 0-15 cm cores collected in fall 2005. In our study, there is little residual NO_3-N present in the entire soil profile even at the highest rates. Similar results were found in a study conducted by Ukrainetz and Campbell (1988) in northwestern Saskatchewan. These workers observed that only when N fertilizer application rates were 200 kg N ha^{-1} or above on bromegrass was there any residual nitrate.

Table 3.16. Residual NO_3 in spring 2006 at three sites of Saskatchewan.

	Sites					
	Colonsay		*Vanscoy*		*Rosthern*	
Depth (cm)	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Fertilizer application method and rate	mg kg^{-1}					
	Dribble Banded					
Control- No Fertilizer	2.6	1.9	3.6	1.7	1.8	1.7
56 kg N & 28 kg P†	2.6	1.8	3.6	1.9	1.7	1.9
112 kg N & 28 kg P	2.6	1.9	2.8	2.0	1.4	1.8
56 kg N	2.4	2.9	3.0	2.2	1.5	1.9
112 kg N	2.7	1.9	2.7	1.7	1.5	1.4
224 kg N	3.0	2.7	4.5*	2.5*	1.6	1.5
	Coulter Injected					
Control- No Fertilizer	2.7	2.0	2.9	2.0	2.1	1.7
56 kg N & 28 kg P	1.8	1.7	2.3	1.8	1.7	1.8
112 kg N & 28 kg P	1.9	1.9	2.5	2.6*	1.6	1.7
56 kg N	2.7	2.0	3.3	2.4	1.4*	1.3
112 kg N	2.8	2.2	2.9	1.6	1.2*	1.2
224 kg N	3.8	3.9*	3.5	2.1	1.6	1.2
LSD $_{(0.05)}$	**1.9**	**1.3**	**1.0**	**0.6**	**0.7**	**1.0**

* Significantly different from control for same application method at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

There was also another study conducted by Read and Winkelman (1981) in which 100 kg N ha^{-1} was applied to crested wheatgrass in southwestern Saskatchewan, and there was no residual N as nitrate after 2 years. However, when 400 kg and 800 kg N ha^{-1} was applied, there was a pool of residual N that lasted for up to ten years on a crested wheatgrass stand in southern Saskatchewan.

3.7.7 Fertilizer N recovery

The proportion (percentage) of added N fertilizer that was recovered in the biomass produced over two years (2005 and 2006) was calculated (Table 3.17), using sum of N uptake of both years, minus N uptake from control treatment, dividing to the rate of applied N fertilizer and multiplying by 100. There was the general trend that when fertilizer application rate increased, the proportion of added N fertilizer recovered decreased. Added P fertilizer did not have a significant (*p≤0.05*) effect on N recovery. Apparent recovery of N in the herbage was highest in the treatment with 56 kg N and 28 kg P, with a coulter injected method of fertilizer application.

Table 3. 17. Percentage of added fertilizer N recovered in forage biomass in 2005 plus 2006 seasons

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		N %	
		Dribble Banded	
Control- No Fertilizer	*NA*	*NA*	*NA*
56 kg N & 28 kg P†	66.6	62.6	79.6
112 kg N & 28 kg P	52.2	66.7	52.5
56 kg N	81.2	80.4	65.3
112 kg N	46.7	59.5	59.0
224 kg N	45.9	57.1	46.3
		Coulter Injected	
Control- No Fertilizer	*NA*	*NA*	*NA*
56 kg N & 28 kg P	101.8	62.4	52.4
112 kg N & 28 kg P	81.9	49.4	39.9
56 kg N	86.6	52.2	43.3
112 kg N	65.0	61.8	37.6
224 kg N	54.4	34.4	43.6

† N - Nitrogen; P - Phosphorus P_2O_5
‡ *NA* - Not Applicable

Power (1980) found that N recovery varied with soil moisture, with rainfall being particularly critical. Good moisture conditions conductive to rapid plant growth and nutrient uptake by roots contributes to high recovery. Ukrainetz and Campbell (1987) found that when 100 kg N ha^{-1} ammonium nitrate fertilizer was applied on smooth bromegrass, the stand had N recovery of 53% in the year of application.

3.7.8 Total Organic Carbon (TOC) and Particulate Organic Matter (POM)

Soil carbon is a major factor affecting soil productivity and represents a significant pool of stored carbon in the ecosystem and globally (Schlesinger, 1997; Schoenau and Campbell, 1996). The treatment effects on the total organic carbon (TOC) concentrations (0 to 15 cm) (Table 3.18) were not significant ($p \leq 0.05$) except for lower TOC % than the control in the 224 kg N ha^{-1} dribble banded treatment at Vanscoy.

Table 3. 18. Soil total organic carbon concentrations (0 to 15 cm) at three sites of Saskatchewan

Sites	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer application method and rate		%	
		Dribble Banded	
Control- No Fertilizer	1.95	1.91	0.90
56 kg N & 28 kg P†	1.84	1.70	0.85
112 kg N & 28 kg P	1.84	1.88	1.10
56 kg N	1.81	1.61	0.90
112 kg N	1.62	1.61	0.94
224 kg N	1.51	1.49	0.80
		Coulter Injected	
Control- No Fertilizer	1.76	1.90	1.17
56 kg N & 28 kg P	1.69	1.72	1.33
112 kg N & 28 kg P	1.77	1.63	0.83
56 kg N	1.57	1.67	0.74
112 kg N	1.65	1.90	0.83
224 kg N	1.54	1.91	0.96
LSD $_{(0.05)}$	**0.66**	**0.32**	**0.43**

* Significantly different from control for same application method at $p \leq 0.05$

† N - Nitrogen; P - Phosphorus P_2O_5

A trend toward lower organic concentration at high rates of N fertilization suggests that the N fertilization may be enhancing decomposition rate. There was also no significant treatment effects on the fraction of TOC identified as POM (Figure 3.8).

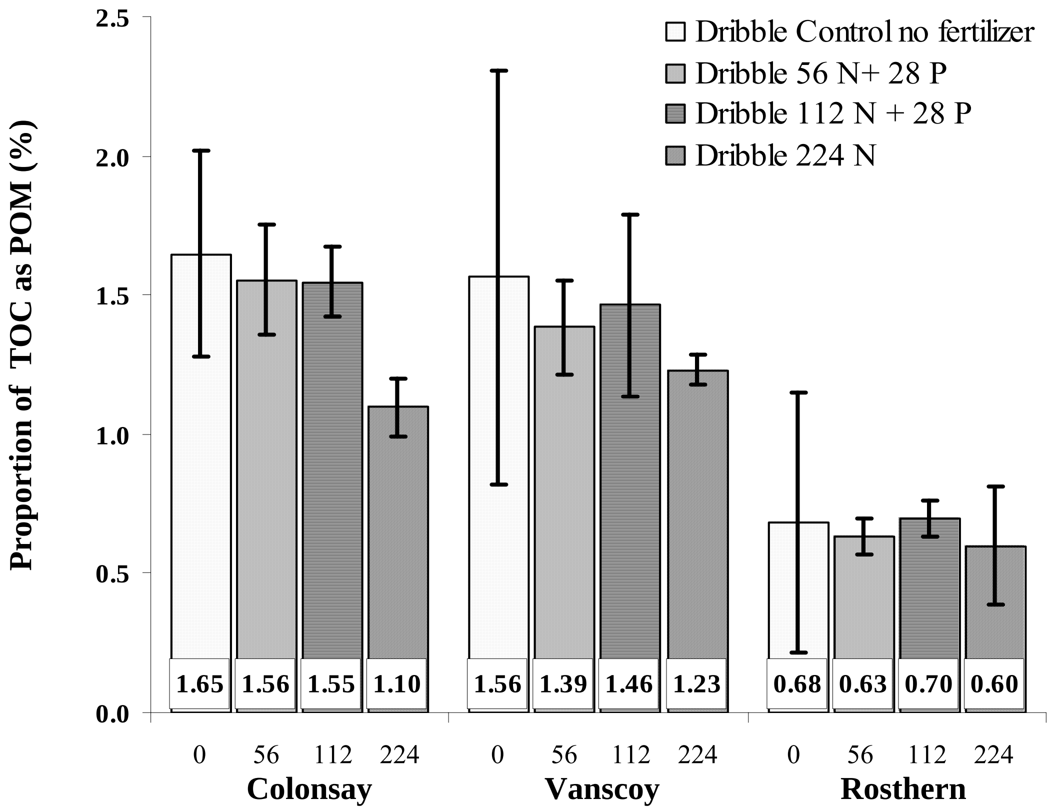


Figure 3. 5. Percentage of TOC comprised of POM fraction at three sites of Saskatchewan. The LSD $_{0.05}$ was 0.91, 0.36 and 0.23 at Colonsay, Vanscoy and Rosthern sites.

In a study by Mensah et al (2003), it was found that with conversion of cropped land to perennial forage grass, the SOC mass in the surface layer was significantly increased after five to twelve years in east-central Saskatchewan.

Research into the effect of long-term fertilization of forage stands in the Black soil zone in Alberta by Nyborg et al. (1997) and Malhi et al. (2001) showed that annual application of N and S fertilizer increased SOC after 11 to 23 years. It seems likely that in the current study, the history of fertilization (one year) is not sufficiently long to produce measurable differences either TOC or POM.

The downward trend in proportion of TOC comprised of POM with added N fertilizer could in fact be a result of enhanced decomposition of POM with N fertilization, from increased microbial activity. This may be due to insufficient time to increase and build up SOC. A one year time-frame is likely not enough to show differences, as Cambardella and Elliott (1992) reported the estimated half-life of grass-derived POM is approximately 13 years.

3.7.9 Soil pH and Electrical Conductivity

Soil pH (Table 3.19) was not significantly different from the control treatments at any of the sites for either of the fall 2005 or spring 2006 sampling times. However, the pH values in spring 2006 were higher than for fall 2005 for the Colonsay site. The change may well relate to the upward movement of $CaCO_3$ from calcareous subsoils. Soil surveyors have noted that horizons that do not normally effervesce, may do so on occasion, especially with strongly calcareous Ca horizons.

Table 3.19. Soil pH (0-15 cm depth) in fall 2005 and in spring 2006 at the three Saskatchewan sites.

	Fall 2005			Spring 2006		
	Colonsay	*Vanscoy*	*Rosthern*	*Colonsay*	*Vanscoy*	*Rosthern*
Fertilizer rate	Dribble Banded					
Control- No Fertilizer	6.9	6.6	6.4	7.6	6.9	6.7
56 kg N & 28 kg P†	6.9	7.2	6.4	7.6	7.2	6.6
112 kg N & 28 kg P	6.9	6.6	6.4	7.6	6.5	6.5
56 kg N	6.8	7.1	6.5	7.6	7.0	6.6
112 kg N	6.8	6.7	6.5	7.6	6.6	6.5
224 kg N	6.8	6.9	6.2	7.6	7.5	6.6
	Coulter Injected					
Control- No Fertilizer	6.8	6.7	6.5	7.6	6.9	6.9
56 kg N & 28 kg P	6.8	7.3	6.4	7.8	7.0	6.6
112 kg N & 28 kg P	6.8	7.2	6.5	7.8	7.4	6.6
56 kg N	6.8	7.1	6.5	7.6	7.3	6.6
112 kg N	6.7	6.6	6.4	7.5	6.5	6.4
224 kg N	6.8	6.7	6.4	7.6	6.7	6.5
LSD $_{(0.05)}$	**0.19**	**0.65**	**0.24**	**0.71**	**0.69**	**0.51**

† N - Nitrogen; P - Phosphorus P_2O_5

This is consistent with general trend to higher EC at Colonsay in the spring of 2006. Some researchers have found that long term N fertilization of grass stands has resulted in some acidification of soil (McCoy and Webster, 1977; Malhi et al., 1998), with depression in pH increased with the amount of applied N (Perl et al., 1982).

There were also no significant differences among treatments in surface (0-15 cm) soil salinity as determined by EC measurement (Appendix, Table A3). Perennial forages can help reduce the effect of salinity, reclaiming areas and controlling the spread of salinity (Malhi et al., 2004). However in our study there were no significant differences in EC; however, the soils were not saline to begin with. It might be expected that greater plant growth from fertilization would favor greater transpiration that would assist in lowering a high ground water table. This could help reduce surface ground water discharge and accumulation of salts at the soil surface.

3.8 Conclusions

The N and P fertilizer treatments produced significantly higher forage dry matter yield than the control in the first year at the Saskatchewan sites. Good moisture, especially in June, likely contributed to yield increases of 1.5 to 2.5 times that of the control. There was no significant difference between the two application methods (surface dribble band vs coulter injected) for any fertilizer treatments. Response to the added P fertilizer in this study was limited. The high rates of N fertilizer application produced the highest yield and, N and P uptake with a residual effect from the N was evident in 2006 at the highest rate (224 kg N ha^{-1}). Increased N uptake by plants with increasing N fertilizer leads to a higher protein yield. The native rangeland in the Mongolia site was less responsive in plant N and P uptake than the Saskatchewan sites, likely due to lower yield potential and a dominance of native range species. Significant rainfall after application of the fertilizer likely contributed to a lack of difference between surface banding and coultering methods of application in this study, as the rainfall would move the surface banded N into the mineral soil. There was no effect in TOC and POM associated with a single year of fertilizer addition, except for a decrease in TOC at the highest N rate at Vanscoy site. Several years of repeated fertilizer application may be required to show significant measurable effects.

4.0 Soil Gas Production and Nutrient Ion Fluxes: Incubation Experiment

4.1 Introduction

Increasing concentration of carbon dioxide (CO_2) in the atmosphere is an environmental concern and one that agricultural producers can help mitigate by sequestering carbon as soil organic matter. Nitrous oxide (N_2O) is another greenhouse gas that is linked to agricultural production, particularly the use of N fertilizer and manure management. Current estimates indicate that N_2O accounts for over 50% of greenhouse gas emissions from agriculture (Kachanoski, 2003). The N_2O may be produced in the soil from both nitrification and denitrification processes in the N cycle. Application of N fertilizer or manures to agricultural soils at rates in excess of crop requirements increases the risk of N_2O emission. The N_2O emissions from agricultural soils are of concern because they represent a loss of N and decrease in amount available to crops and also contribute to global warming and the destruction of ozone layer (Crutzen, 1981). Another important dynamic process in the soil N cycle is mineralization. N mineralization is the conversion of organic N to the plant available inorganic forms of ammonium and nitrate. Ion exchange resin membranes placed in direct contact with the soil over a period of time will adsorb inorganic N released by mineralization and can be used as a predictor of soil N supply power (Qian and Schoenau, 2005).

This section of the thesis addresses the effect of N and P fertilization of the three Saskatchewan forage sites in the spring of 2005 on the release of soil CO_2 and N_2O, and the supply rates of bioavailable plant nutrients using soil cores collected from the field in the fall of 2005. Measurement of soil gases produced and supply rates of ammonium, nitrate and phosphate in were made in intact cores incubated in the laboratory for two weeks.

4.2 Materials and Methods

The carbon dioxide (CO_2) and nitrous oxide (N_2O) measurement and PRS ™ probe analysis of soil nutrient ion supply rates were conducted on the intact soil cores removed from the sites in the fall of 2005 as described in section 3.4. Field sampling was conducted at Colonsay, Vanscoy and Rosthern sites with PVC pipe to obtain intact soil cores, and the incubation for two weeks was conducted prior to processing the soils for analysis as described in section 3.4.

4.2.1 Incubation protocol

Intact PVC cores (10 cm in diameter and 15 cm in length) were sampled from each treatment plot in the second week of October of 2005 close to freeze-up. The intact soil cores were immediately transported from the field to the laboratory and stored at 4ºC. The cores were then placed in an incubation chamber with electronically controlled environmental settings. The chamber was set for 16 hr at 25ºC (day) and 8 hrs at 18ºC (night). The cores were incubated for one week at field capacity moisture content. After one week, 70 mL of water was added to the cores to compensate for drying in the chamber and to bring back them back to field capacity and then they were incubated for another week. Due to previous analysis which showed no significant difference in yield between fertilizer application methods, we used only treatments with the dribble banded method of fertilizer application in the incubation and also excluded the 56 kg N ha^{-1} and 112 kg N ha^{-1} N only treatments. Therefore treatments included were control, 56 kg N and 28 kg P_2O_5 ha^{-1}, 112 kg N and 28 kg P_2O_5 ha^{-1} and 224 kg N ha^{-1}. During the incubation, ion exchange resin membrane (Plant Root Simulator™) probes were installed and used to measure nutrient ion supply rates while CO_2 and N_2O gases were collected and measured using gas chromatography. (Figure 4.1)

Figure 4. 1. Intact core with PRS™ probe inserted and ready to be placed into chamber.

4.2.2 Carbon dioxide and nitrous oxide gas sampling protocol

For the incubation experiment, intact PVC cores were placed into a two piece container made up of two PVC pipes each 15 cm in diameter and 18 cm in length and two plastic caps (Nelson, 2003) (Figure 4.2).

Figure 4. 2. Sealed chambers containing intact soil cores with syringe inserted ready for gas sampling

The two-part PVC chamber was joined together by a rubber airtight flange fastened with hose clamps. A rubber septum was inserted into the top cap of the container so that gas samples could be extracted. The PVC containers were capped and sealed daily for one hour. A syringe (20 mL) was placed through the rubber septum and was used to transfer a 20 cm^3 gas sample into an evacuated vial (10 cm^3) every 4th day at the same time for two weeks. Before sampling commenced, three ambient 20 cm^3 CO_2 samples were placed into three 10 cm^3 evacuated vials. After sampling, the tops of the PVC containers were removed to allow natural airflow between the chamber and the intact soil cores.

4.2.3 Gas analysis

Carbon dioxide concentrations were determined using a Varian CP-2003 micro-GC with twin micro-thermal conductivity detectors. An on-board vacuum pump pulled the sample into a He gas stream with an injector temperature of 110º C. The sample CO_2 was separated using a Hayesep column at 50º C. For the nitrous oxide, the injector temperature was 70^o C in front and 70^o C in back. The sample N_2O was separated by a Poraplot™ Q column and sampled by a Compupal™ autosampler.

4.2.4 Bioavailable nutrients using plant root simulator (PRS™) probes

The bioavailable nitrate, ammonium, and phosphate supply rates were determined using Plant Root Simulator (PRS™) probes (ion exchange resin membranes) according to the procedures outlined in Qian and Schoenau (2002). The PRS™ anion probes were initially soaked in distilled water for 24 hours. The probes were then charged for 2 hours in 0.5 M $NaHCO_3$ to saturate the exchange sites with bicarbonate as the counter ion. This was repeated a total of 4 times. The probes were then washed twice and stored in distilled water, after which they are ready for insertion into the soil. Cation PRS™ probes were charged by soaking in 0.5 *M* HCl for 2-4 hours to saturate the exchange sites with H^+ ions.

The anion and cation probes were inserted into the intact soil cores collected from the field just before placement of the cores into the incubation chambers. After two weeks of incubation, the probes were removed from the soil and placed into plastic Ziplock™ bags for transport to the laboratory. After transport, the probes were washed of all remaining soil particles and placed into a clean Ziplock™ bag and treated with 20 mL of 0.5 *M* HCl for one hour to elute the sorbed ions from the membrane surface. The eluent was then placed in a 7 dram vial, capped, and stored at 4º C until it was colorimetrically analyzed for NO_3 – N, NH_4 – N and PO_4 – P using the Technicon™ Auto-analyzer II.

4.3 Statistical Analysis

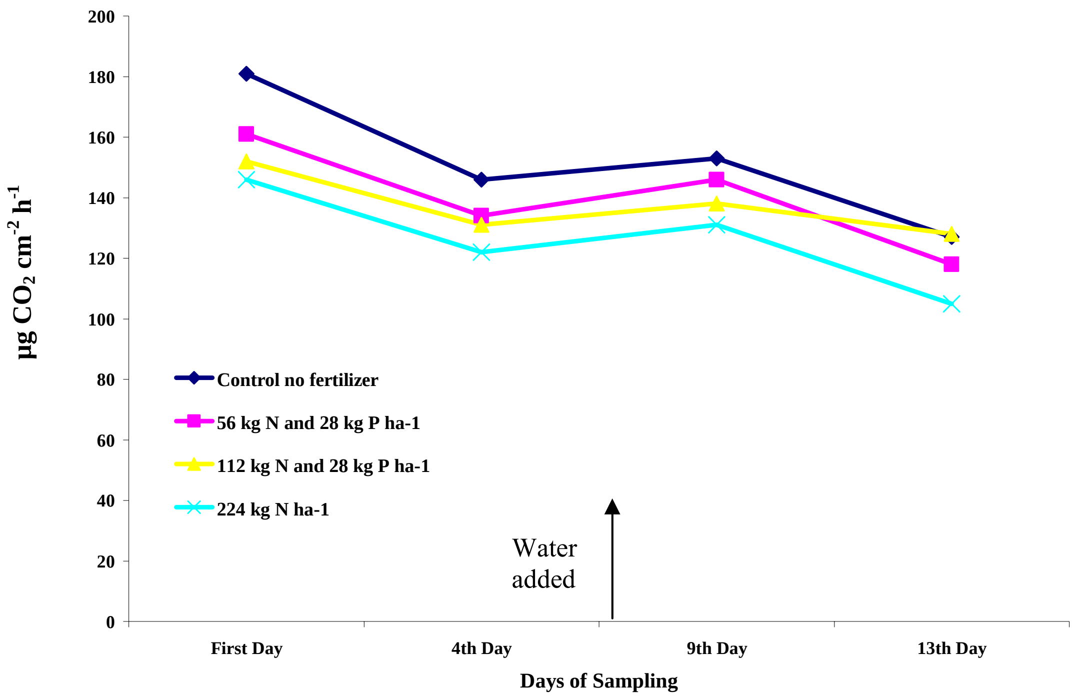
This experiment was set up as a randomized complete block design. Due to a non-normal distribution obtained from the nitrous oxide flux measurements, a log transformation was required before analysis of variance (ANOVA) could be completed (SPSS 14.0, 2005). A significant ANOVA result indicates that at least one of the treatments mean was different than control (Zar, 1999). Mean separation was done using least significant difference (LSD) at $\alpha = 0.05$ unless otherwise state

4.4 Results and Discussion

4.4.1 CO_2 evolution

Average respiration rates were similar among the fertilized treatments at all of the sites and the pattern of CO_2 evolution measured over a two-week period showed a similar trend at the three sites (Appendix, Table A1). The CO_2 evolution data for the Rosthern site is shown as an example (Figure 4.3). The CO_2 evolution decreases in the first days as the cores dry out and substrate is utilized (Figure 4.3). When the cores dry out the activity of the microbial biomass decreases and less CO_2 is respired. Addition of water to bring the soil to field capacity on Day 7 is responsible for the increase in respiration rate from day 4 to day 9. Wet-dry cycles tend to stimulate CO_2 production the soil, as desiccation causes the death of soil microbial biomass, which then acts as a substrate for new microbial activity when the soil is rewetted. This phenomenon is also known as the "Birch effect" (Birch, 1958). In other studies by de Jong (1981) and Fierer and Schinel (2002) they, noted that CO_2 evolution and microbial respiration are closely linked to soil moisture.

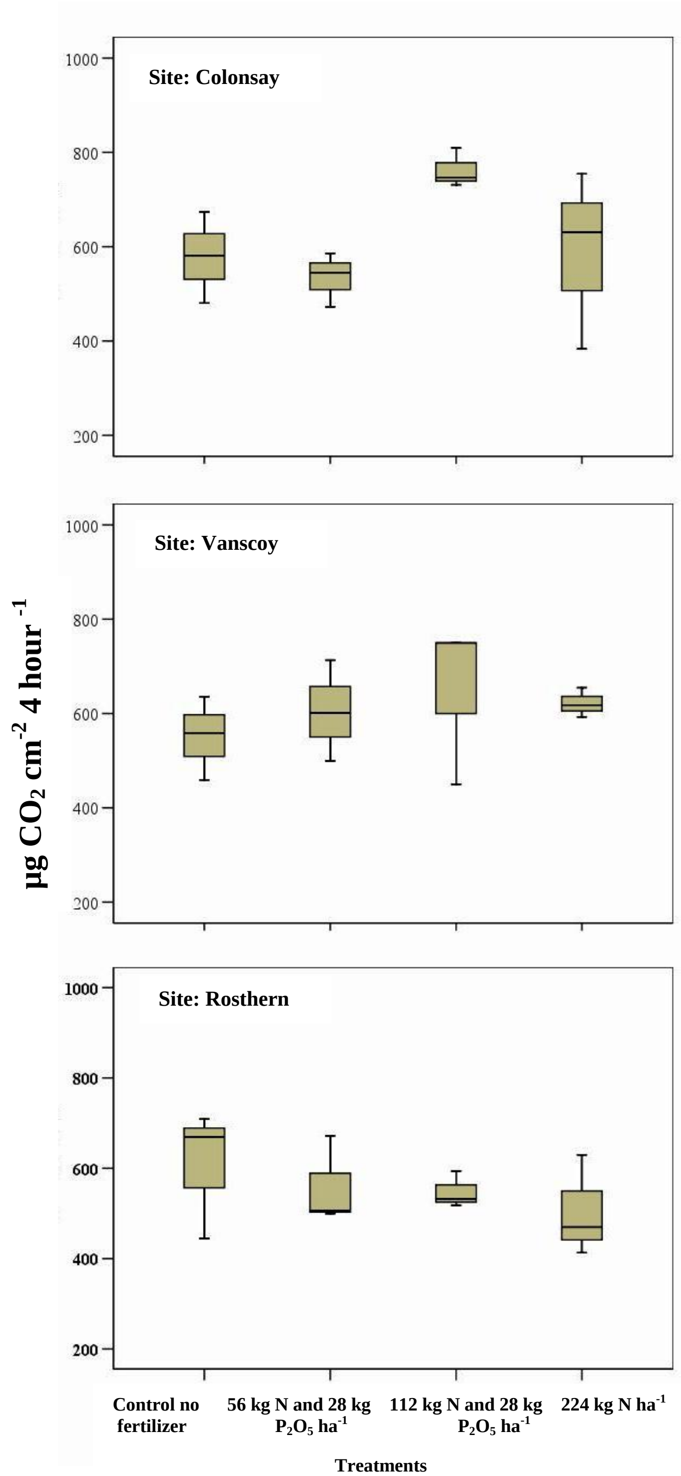
Figure 4. 3. Mean CO_2 evolution rate from intact soil cores (Rosthern site), sampled in a sealed container after one hour (µg CO_2 cm^{-2} h^{-1}) every 4 days over a two week period



However, the relationships between soil CO_2 respiration and water content or temperature are nonlinear (Bunnell and Tait, 1974).

Over the two weeks of incubation there was no significant ($p \leq 0.05$) difference in the cumulative amount of CO_2 evolved (Figure 4.4) among the treatments at all three sites except the 112 kg N plus 28 kg P_2O_5 ha^{-1} treatment at Colonsay site, which

Figure 4. 4. Cumulative CO_2 evolution (sum of four one hour measurements made) over a two week period from intact soil cores from the three sites



had significar While

fertilizer addition in spring of 2005 is suggested to have stimulated microbial activity as hypothesized in section 3.7.8 and observed by others (de Freitas et al., 2003), it appears that by the fall the fertilization effect likely has diminished, and readily available substrate such as POM for the soil microbial biomass to use for growth may be depleted by fall of the year.

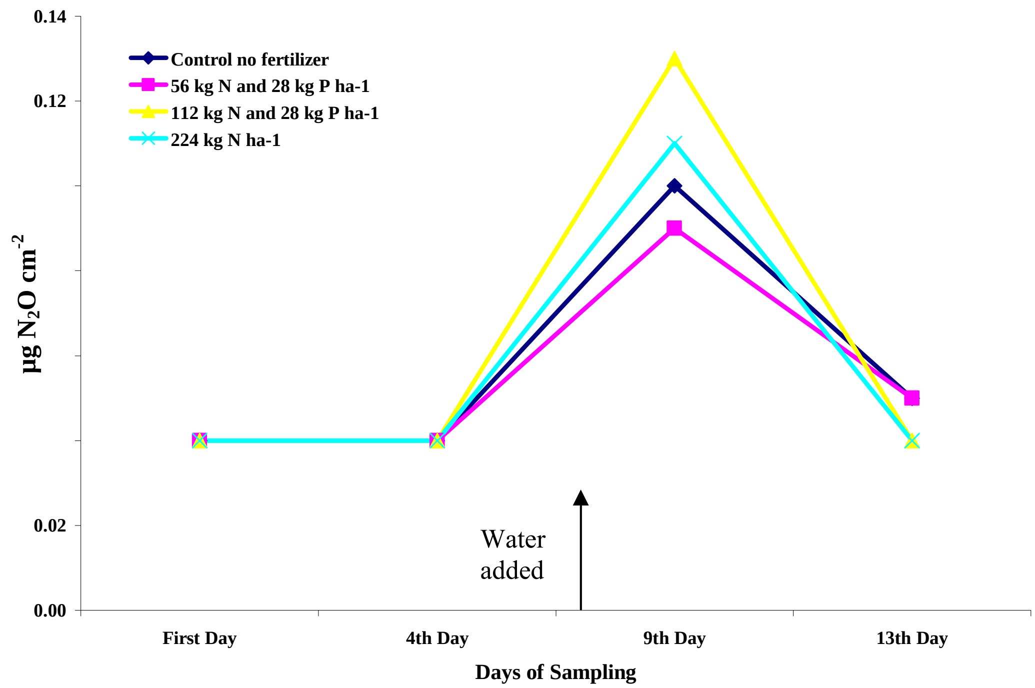
4.4.2 N_2O evolution

Average N_2O production rates were similar among the treatments at all the sites and followed a similar pattern. The pattern of N_2O evolution measured over a two-week period shows the same trend at the three sites (Appendix, Table A1). The N_2O fluxes are shown in Figure 4.5 for the Rosthern site as an example. The large increase in N_2O production from Day 4 to Day 9 is likely related to the addition of water on Day 7. The added water would contribute to development of anaerobic microsites in the soil, in which denitrification and nitrous oxide production occurs. When soil dries, the N_20 evolution rates decreased. Treatments with higher rates of N application tended to have greater N_2O evolution than control and treatments with lower rates of applied N fertilizer. However there were no significant ($p \leq 0.05$) differences in N_2O evolution between treatments at any of the sampling times for any of the sites.

Bedard-Haughn et al. (2006) noted that there was no impact on N_2O evolution when N fertilizer was applied (72% as 46-0-0 and 28% as11-52-0 at a rate of 135 kg ha^{-1}) to a cultivated wetland soil in central Saskatchewan.

Incubation of the intact soil cores did not show any significant differences in cumulative N_2O evolution amongst the treatments (Figure 4.6). The amount of cumulative N_2O produced at Rosthern site was lower than Colonsay and Vanscoy sites (Appendix, Table A1).

Figure 4. 5. Mean N_2O evolution rates from intact soil cores (Rosthern site), sampled in a sealed container after one hour ($\mu g\ CO_2\ cm^{-2}\ h^{-1}$) every 4 days over a two week period



4.4.3 Nutrient supply rates

Nutrient supply rates measured by the PRS™ probes were not significantly different among the fertilization treatments, except for NO_3-N at Rosthern (*p≤ 0.05*) in the 224 kg N ha^{-1} treatment. A similar trend was observed at the Vanscoy site. The NH_4^+-N and P supply rates did not show any differences (*p≤0.05*). These findings are consistent with lack of residual effects on yield and N uptake in 2006, except at the high (224 kg N ha^{-1}) rate. Lack of significant difference in ion supply rates agree with lack of significant effect of fertilization on CO_2 and N_2O production. The effect of this one time treatment appears to have diminished by fall, with the possible exception of the highest rates.

Figure 4. 6. Cumulative N_2O evolution (sum of four one hour measurements) over a two week period from intact soil cores from the three sites

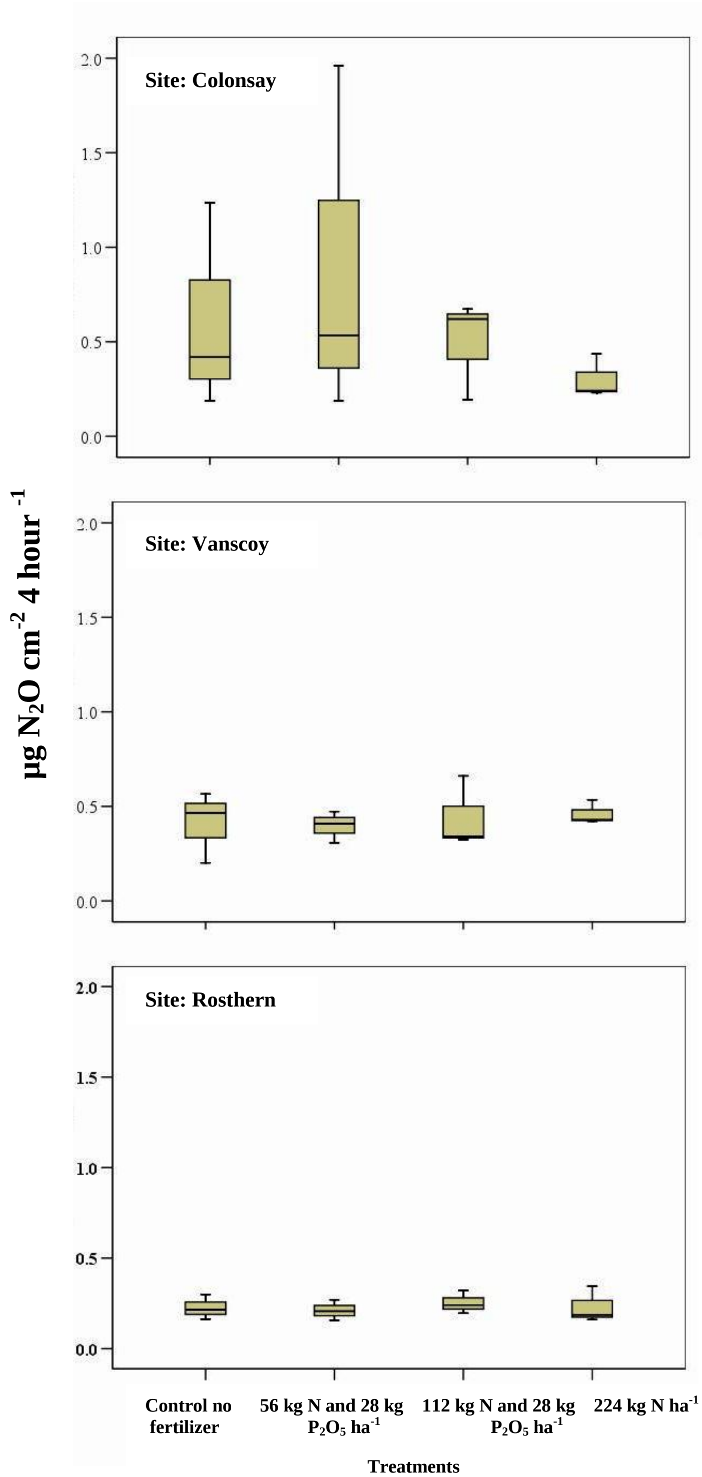


Table 4. 1. Supply rates measured by PRS probes over a two week period

Fertilizer rate	Colonsay NO3	Colonsay P	Colonsay NH4	Vanscoy NO3	Vanscoy P	Vanscoy NH4	Rosthern NO3	Rosthern P	Rosthern NH4
	Sites								
	$\mu g\ cm^{-2}$								
Control no fertilizer	33.18	0.23	0.22	41.87	0.17	0.07	16.34	0.87	0.62
56 kg N and 28 kg P_2O_5 ha^{-1}	31.46	0.10	0.17	38.06	0.32	0.08	24.68	0.60	0.04
112 kg N and 28 kg P_2O_5 ha^{-1}	6.87	0.87	0.17	48.31	0.46	0.09	15.83	0.44	0.12
224 kg N ha^{-1}	24.17	0.15	0.18	64.99	0.22	0.08	58.76*	0.65	0.22
LSD $_{(0.05)}$	**37.3**	**1.2**	**0.1**	**39.8**	**0.4**	**0.2**	**27.6**	**1.0**	0.9

** Significant at the 0.05 probability level.*
Note: *Measured by ion exchange resin (PRS ™ Probes) over a two week incubation period*

The PRS™ sorbed NH_4^+-N at these sites was not significantly affected by fertilization. This is most probably due to the process of nitrification happening at a high rate, resulting in low amounts of sorbed NH_4^+-N. The P supply rates measured by the PRS™ probes at Colonsay, Vanscoy and Rosthern did not show any response to the treatments. This is consistent with the extractable P concentrations which were also not significantly affected by N fertilization.

4.5 Conclusion

There were few significant differences in CO_2 and N_2O production measured five months after fertilizer application at the end of the growing season as a result of fertilizer treatment. However it is clear that moisture is one of the major drivers affecting CO_2 and N_2O production. Higher additions of N fertilizer that result in plants using 50% (or less) of the applied N appear to result in the residual being retained in the soil, and not given off as N_2O. Application of the high rates of N fertilizer (224 kg N ha^{-1}) increased potential supply rates of NO_3-N in soil and a residual benefit in increasing yield in the 2006 season.

5.0 General Discussion and Recommendation

The general objective of this study was to evaluate the effects of a single application of N and P fertilizer on forage quantity and quality and soil properties in hayland and native rangeland to assess the effectiveness of fertilization in rejuvenation. Surface N banding in the spring produced significant increases in forage dry matter yield by about 1.5 to 2.5 times greater yield than the control along with increased protein concentration at three sites in Saskatchewan. Rates of about 50 kg N ha^{-1} were effective, and produced the greatest incremental yield increase while higher application rates mainly resulted in additional protein concentration. The N and P fertilizer application had a limited effect on the soil chemical and physical properties as a whole as measured in the fall of the season of application. The exception was the high rate of N (224 kg N ha^{-1}) application which left residual NO_3-N for the following year and contributed to a yield response in 2006. Previous studies suggest that N is the major limiting nutrient in grass hay pastures (Sedivec and Manske, 1990; Berg and Sims, 1995; Malhi, et al., 2004) and the results of our study support this, as responses to P in both the Saskatchewan sites and the Mongolian site were limited.

Yield was generally maximized at ~ 100 kg N ha^{-1} rate and meadow brome grass tended to yield better at the intermediate rate of fertilizer applications (112 kg N or 112 kg N and 28 kg $P_2O_5{}^{-1}$) than the low rate fertilizer treatments (56 kg N or 56 kg N and 28 kg P_2O_5 ha^{-1}). There is a need for more precise determination of the economical N rate application based more N increments from zero up to 50 kg N ha^{-1}in future research.

There was no response to the added P fertilizer in this study. There was no significant difference between the two application methods (surface dribble band vs coulter injected) for any fertilizer treatments. Significant rainfall after application of the fertilizer likely contributed to a lack of difference between surface banding and coultering methods of application in this study, as the rainfall would move the surface banded N into the mineral soil. Evaluation of surface placement performance in drier conditions such as in southern Saskatchewan is needed.

In our study there was little residual NO_3-N present in the soil profile, with the grass systems being effective in recovery of fertilizer N applied at low rates, and in recycling excess N the year after when higher application rates were used. Similar results were found in a study conducted by Ukrainetz and Campbell (1988) in northwestern Saskatchewan. They reported that only when N fertilizer application rates were around 200 kg N ha^{-1} on a bromegrass stand was there any residual nitrate. Added P fertilizer did not have a significant effect on N recovery. Apparent recovery of N in the herbage was highest in the treatment with 56 kg N plus 28 kg P ha^{-1}, as with a coulter injected method of fertilizer application over the 2 years of study (2005 and 2006). The response to other macronutrients like S and K should be investigated in grass dominated pastures.

Grassland and native rangeland soils are considered to be net carbon sink in the environment and long-term fertilization can influence sequestration and retention of carbon. However in this study, the year of fertilization did not increase TOC or POM amounts in the 0-15 cm soil layer. In fact there was a trend towards lower concentration in the top 15 cm soil that may be due to the fertilizer N enhancing the decomposition rate. Evaluation of the effect of two or more years of fertilization is recommended.

The production of CO_2 and N_2O was not significantly affected by fertilization when measured in the fall at the end of growing season in incubated cores. Further research is required as there was slight trend towards increased N_2O production at higher rate (112 kg N and 224 kg N ha^{-1}) of N fertilizer application, and the rate of N_2O may have been significantly higher if it was measured shortly after N fertilizer in the spring. There is almost no research on CO_2 emissions from fertilized grassland in either western Canada or in Mongolia. Suggested areas for further research also include studying the relationship between N supply and POM decomposition rates, and the influence of N fertilization on belowground biomass from roots in grassland system, as the current study just assessed above ground production effects.

6.0 Conclusion

The addition of N fertilizer appears to be an effective way of rejuvenating a grass dominated forage stand. Significant increases in forage dry matter yield and crude protein were observed in forage yield in Saskatchewan meadow bromegrass stands and Mongolian native rangeland, whether the fertilizers were surface dribble banded or coultered. However, N concentration in plant biomass was not significantly affected at the Mongolia site and N uptake did not increase with increasing rate of application as at the Saskatchewan site. This may be due to the diverse plant composition and wide variety of native species in Mongolian native rangeland. Adequate precipitation during growing season in 2005 and 2006 at the Saskatchewan and Mongolian sites was a factor contributing to the good yield responses to fertilization that were observed. Rainfall after application of the fertilizer in the spring likely contributed to a lack of difference between surface banding and coultering methods of application in this study, as the rainfall would move the surface banded N into the mineral soil. Based in results of this study, a large response to P fertilization is not anticipated in similar grasslands. A carryover effect of high rate (> 112 kg N ha^{-1}) of N fertilizer was detected in the second year, and was consistent with the observed elevation in nitrate concentration and supply rates in the fall of the year of application. However, there was no effect on TOC and POM. Cumulative mean CO_2 and N_2O production measured five months after fertilizer application at the end of the growing season was not significantly affected by fertilization. However, it is clear that moisture is one of the major drivers of CO_2 and N_2O production, as gas production was stimulated by addition of water during the incubation.

According to our study, the application of ~50 kg N ha^{-1} using a surface dribble band method would appear to be an economically effective strategy for rejuvenation of a grass dominated forage stand. Fertility management has often been over looked on hay and pasturelands, but because of the benefits to forage production and quality observed in this study, it is recommended as a way to increase production of a sustainable supply of high quality forage. Rejuvenation of a grass-dominated forage stand by adding the appropriate amount of N fertilizer enhances yield, protein, and improves feed quality. It is anticipated that after several years, benefits would also accrue in increasing soil organic matter and nutrient supply power. An effective method to increase dry matter production in pasture or forage is appropriate fertilization management.

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APPENDIX

Table A1. CO_2 and N_2O production rate means and least significant difference (LSD) values

Treatments	Colonsay				
	μg CO_2 cm^{-2} $hour^{-1}$				
	First day	4^{th} day	9^{th} day	13^{th} day	Cumulative
Control no fertilizer	162	135	166	116	579
56 kg N and 28 kg P ha^{-1}	138	134	150	112	535
112 kg N and 28 kg P ha^{-1}	168	228	209	158	763
224 kg N ha_{-1}	168	137	169	116	589
LSD($_{0.05}$)	***71***	***58***	***56***	***42***	***211***
	μg N_2O cm^{-2} $hour^{-1}$				
Control no fertilizer	0.06	0.06	0.45	0.04	0.61
56 kg N and 28 kg P ha^{-1}	0.05	0.05	0.75	0.04	0.89
112 kg N and 28 kg P ha^{-1}	0.07	0.06	0.33	0.04	0.50
224 kg N ha^{-1}	0.10	0.08	0.09	0.04	0.30
LSD($_{0.05}$)	***0.065***	***0.050***	***1.056***	***0.008***	***1.061***
	Vanscoy				
	μg CO_2 cm^{-2} $hour^{-1}$				
Control no fertilizer	144	133	158	117	551
56 kg N and 28 kg P ha-1	125	170	165	144	605
112 kg N and 28 kg P ha-1	134	186	190	140	650
224 kg N ha-1	167	161	161	133	622
LSD($_{0.05}$)	***97***	***45***	***49***	***30***	***211***
	μg N_2O cm^{-2} $hour^{-1}$				
Control no fertilizer	0.04	0.07	0.22	0.08	0.41
56 kg N and 28 kg P ha^{-1}	0.04	0.07	0.23	0.05	0.40
112 kg N and 28 kg P ha^{-1}	0.05	0.12	0.24	0.04	0.44
224 kg N ha^{-1}	0.07	0.21	0.13	0.06	0.46
LSD($_{0.05}$)	***0.016***	***0.113***	***0.291***	***0.039***	***0.270***
	Rosthern				
	μg CO_2 cm^{-2} $hour^{-1}$				
Control no fertilizer	181	146	153	127	607
56 kg N and 28 kg P ha^{-1}	161	134	146	118	559
112 kg N and 28 kg P ha^{-1}	152	131	138	128	548
224 kg N ha^{-1}	146	122	131	105	504
LSD($_{0.05}$)	***79***	***46***	***44***	***40***	***198***
	μg N_2O cm^{-2} $hour^{-1}$				
Control no fertilizer	0.04	0.04	0.10	0.05	0.23
56 kg N and 28 kg P ha^{-1}	0.04	0.04	0.09	0.05	0.21
112 kg N and 28 kg P ha^{-1}	0.04	0.04	0.13	0.04	0.25
224 kg N ha^{-1}	0.04	0.04	0.11	0.04	0.23
LSD($_{0.05}$)	***0.005***	***0.013***	***0.132***	***0.009***	***0.139***

Table A2. Residual NH_4 in spring 2006

	Sites					
Sites	*Colonsay*		*Vanscoy*		*Rosthern*	
Depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60
Fertilizer application method and rate			Dribble Banded			
Control- No Fertilizer	2.8	1.8	2.5	1.9	1.9	2.5
56 kg N & 28 kg P†	2.4	2.0	2.1	2.1	2.2	2.3
112 kg N & kg 28	3.1	2.0	2.1	2.0	2.1	2.3
56 kg N	3.0	2.1	2.0	1.9	3.2	3.3
112 kg N	2.5	2.6	2.4	2.2	2.4	2.6
224 kg N	2.5	3.0*	2.6	2.5	2.3	2.5
Fertilizer application method and rate			Coulter Injected			
Control- No Fertilizer	6.8*	2.1	2.7	2.3	2.5	2.6
56 kg N & 28 kg P	2.0	2.2	2.2	2.2	2.7	3.1
112 kg N & kg 28	1.9	2.1	1.9	1.9	2.1	2.2
56 kg N	2.4	1.9	2.0	2.0	2.1	2.0
112 kg N	2.5	2.6	2.4	2.2	2.7	3.2
224 kg N	2.7	2.7	2.9*	2.1	3.0	2.6
LSD $_{(0.05)}$	**4.0**	**0.9**	**0.9**	**0.6**	**1.4**	**1.4**

* Significant at the 0.05 probability level

† N - Nitrogen; P - Phosphorus P_2O_5

Table A3. Soil Electrical Conductivity.

Years	2005			2006		
Sites	*Colonsay*	*Vanscoy*	*Rosthern*	*Colonsay*	*Vanscoy*	*Rosthern*
			dS m^{-1}			
Fertilizer application method and rate			Dribble Banded			
Control- No Fertilizer	0.14	0.14	0.10	1.30	0.09	0.08
56 kg N & 28 kg P†	0.14	0.15	0.10	0.28	0.11	0.07
112 kg N & kg 28	0.12	0.13	0.09	0.91	0.07	0.06
56 kg N	0.15	0.14	0.09	0.69	0.10	0.07
112 kg N	0.14	0.12	0.09	0.21	0.07	0.06
224 kg N	0.12	0.17	0.11	0.20	0.16	0.06
			Coulter Injected			
Control- No Fertilizer	0.15	0.12	0.11	0.23	0.09	0.10
56 kg N & 28 kg P	0.13	0.19	0.10	0.28	0.08	0.06
112 kg N & kg 28	0.15	0.13	0.09	0.26	0.09	0.07
56 kg N	0.13	0.15	0.08	0.35	0.12	0.06
112 kg N	0.14	0.11	0.08	0.91	0.07	0.07
224 kg N	0.16	0.14	0.10	0.32	0.08	0.07
LSD $_{(0.05)}$	**0.03**	**0.06**	**0.02**	**1.04**	**0.06**	**0.04**

† N - Nitrogen; P - Phosphorus P_2O_5